



Impact de l'expérience immersive sur la prise en compte du kansei en design industriel amont

Vincent Rieuf

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Impact of the Immersive Experience on Kansei During Early Design

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GENERAL INTRODUCTION

By the comparative study of traditional early design activity and immersive early design activity, this research work proceeds, to evaluate and model the *Virtual Kansei Design* activity. This study essentially relates to the application and experimentation of fundamental theories through the design and evaluation of two industrial design conjoint tools:

- **Spatial Immersive Moodboards** are inspirational spatial immersive environments dedicated to the understanding of a stylistic trend and designed to replace and augment the traditional moodboards.
- **Spatial Immersive Sketching** is a generational environment enabling the designer to create, erase, manipulate and generally interact with a three dimensional drawing intended for the first idea sketches of the design process.

This research aims to develop tools and an immersive early design workflow enabling the designer to anticipate Kansei (holistic relationship between the designer and the product user) in order to optimize the strategic stylistic choices, and maximize the extent to which the designer can be inspired and can generate concepts while augmenting the ability of the designer to produce aesthetic and innovating concepts.

1.1 AIMS & OBJECTIVES

This research work withholds two conjoint objectives: the industrial objective and the academic objective. The research & action method adopted by the *Laboratoire de Conception de Produit et d'Innovation (NPDIL)* in Paris, supervising this thesis, encourages a close collaboration between industrial and research environments. It thus guarantees that the applied research answers a definite industrial problematic while developing objective knowledge. Industrial needs, methods and techniques that integrate industrial feedback are thus developed. This virtuous circle generates innovative and adapted results. Each of the two objectives are detailed in the following sections.

1.1.1 ACADEMIC OBJECTIVES: UNDERSTANDING THE EMOTIONAL ACTIVITY OF THE INDUSTRIAL DESIGNER WORKING IN IMMERSIVE ENVIRONMENT

This study aims to investigate how the industrial designer's activity can be empowered by immersion and virtual reality technologies during the early industrial design process. From end to end of the design process, the future product is represented by the designer in order to assess and forecast the projects evolution. These representations address the form, the color and the texture factor of the product, but also more important and abstract components such as sensation, emotion and experience. Given the spatial nature of the final product and the growing complexity in the general understanding of its relation with the end-user, it is crucial that we explore and understand how traditional early representations and the emotional process can be augmented by immersive technologies.

The academic objectives of this research are :

- to study the semantic and emotional impact of immersion on the traditional inspiration process in design.
- to explore the modifications in the designer's experience induced by immersion, in the early industrial design workflow.
- to observe the impact of immersion in the early industrial design workflow on the semantic and emotional link between the designer and the product end-user.
- to identify the consequences of immersion on originality, aesthetic and intelligibility of the out-coming design concepts and on the end-user's feeling.

1.1.2 INDUSTRIAL OBJECTIVES: INSPIRATIONAL AND GENERATIONAL TOOLS

The continuous contact between our research team and professional industrial designers enabled the identification of clear industrial objectives. In this research work the objectives are intended to provide the industrial designers with an innovative workflow, adapted to their needs and aimed at optimizing their activity.

The industrial objectives of this research are:

- Design immersive workflow to assist the industrial designer in his work.
- Develop a method for user experience assessment.
- Apply this method in the development of a technological platform.

- Assess this method and platform and provide specifications for future development.

1.2 RESEARCH QUESTION

Given the fact that a large majority of industrial designers answer their design brief by a physical product, it is crucial that we understand the process that transforms a design problem into a product solution. We will define the *externalization process* as the transformation of embodied ideas into physical representations. By definition, the externalized process is the transition of a design concept from the human support onto another. The externalization process is preceded by the gathering and capturing of inspirational information. Switching information from a support to another fundamentally modifies this information in its core. The designer needs a tool that enables engaging inspiration and easy bodily encryption of the design concept onto an engaging and modular support.

Therefore, we raise the research question: **How can the early design process be augmented by immersion in a spatial industrial design workflow?**

1.3 CONTRIBUTION OF STUDY

The foremost contributions of the study, both in scientific and industrial communities can be summarized as follows:

- A model of traditional and immersive early industrial design workflow, describing the changes induced by the immersive spatialization of the industrial designers' workflow.

This model is based on our empirical study and the analysis of the data produced by experimentations. The empirical study is based on an innovative research framework developed in adequacy with our academic objectives. Ultimately this model renders the industrial design activity more explicit.

- Two operational immersive early design tools (immersive moodboards & immersive sketching) as well as specifications for the design of future immersive tools dedicated to immersive inspirational and generational early industrial tools.

Our research leads us to develop an immersive early design workflow composed of two immersive conjoint tools. Further than developing these tools, the study analyses the design experience enabled by the immersive early design workflow. This involves the development of a specific design

experience analysis method. This method describes the emotional and pragmatic components of the experience (physiological, cognitive and behavioral databases), and the impact of immersion on the quality of the design concepts produced. The study finally assesses the proposed early design workflow and identifies requirements for future development.

1.4 ORIGINALITY OF THE RESEARCH

This study presents an original approach to five different extents: ① the observation of emotional activity during the act of immersive early industrial design, ② the use and combination of psychology, physiology and behavioral multidimensional model in design research, ③ the update of traditional methods and models linking the designer to his tools, ④ the identification of transfers between inspirational and generational phases in early industrial design and ⑤ the description of the semantic and emotional link joining the designer to the end-user .

- Observing the emotional activity during the act of immersive early industrial design.

Contemporary studies considering that emotion and design are product-user centered rather than product-designer centered. We have bridged the research gap by proposing an empirical study of the emotional state of the designer during his inspiration and generation activity. This research point of view on design research is guided by the lack of adequate digital immersive tools and method adapted to the early design activities.

- Using psychology, physiology and behavioral multidimensional model in design research.

For the purpose of the research, we have used an innovative approach to depict the designer's experience. The study brings an innovative emotion and experience evaluation model by combining psychological, physiological and behavioral. These techniques are presently explored by Japanese research laboratories. One of the originality of the study is the combination of abroad research framework with a traditionally European framework in order to create an innovative research approach.

- Updating the models linking the industrial designer to his tools.

We have developed research on how the digital approach can assist in managing fuzzy information and help divergence while responding to the need of the designer for freedom and immediacy in their creative process. The contemporary tendency to digitalize the tools toward optimization has

modified the design activity and with it the designer's needs. Computer Aided Design is already up to speed and 3D software helps in the definition and refinement of the finite geometry of industrial products. However, there scarcely exists any digital assistance for the early design process and even less methodologies to build this assistance.

- Identifying the impact of immersion on the transfers between inspirational and generational phases in early industrial design.

Through its analysis, this research work points out some key features of the moodboards that impact the designer and his creations. The early design process is composed of an inspirational phase during which the designer gathers information on the context of his mission. This information provides a significant part of the information on which the generation phase is based. In this process the industrial designer composes a new product namely by exploiting the information he has collected. We have detected that particular semantic and emotional attributes are more likely to be collected and implemented in the concept design.

- Considering the spatial immersive workflow as a better vector for the semantic-emotional link joining the designer to the end-user.

The take of this research work on the designer to end-user relationship results in the characterization of immersive early design as an innovative vector for emotional design. This helps the designer to express their intention to the end-user through the product.

- Considering immersive early design as an enactive experience

An original aspect of our work is to integrate the industrial designer's experience as a prior factor for the optimization of the design process. This results in an innovative natural interaction with spatial immersive moodboards and sketching. This contributes to the empowerment of the industrial designer and the integration of digital tools to his workflow.

- Inter-disciplinary positioning

The originality in the approach is mainly due to our positioning. By grouping industrial design research with advanced emotion measurement methods in virtual environments, we have undertaken an unusual framework presently scarcely explored.

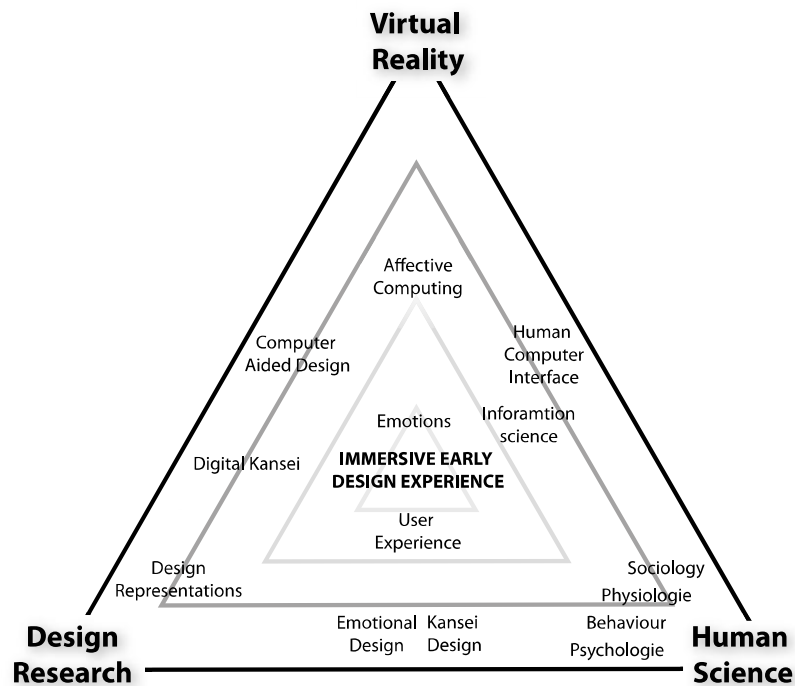


Figure 1 - Understanding the immersive early design experience as an interdisciplinary topic

This section shows how the positioning of this research work is linked to three new but expanding domains. Gathering the Design Research, Virtual Reality and Human Sciences enables us to model the immersive early design experience and its impact on the designer's activity, its outcomes and their impact on the end-user's experience. (cf. Figure 1)

The next section contributes to clarifying the structure of the document.

1.5 STRUCTURE OF THE DOCUMENT

Chapter I Context

Chapter I introduces how virtual reality has evolved away from one another during the last 50 years and how this gap raises question on the experience of an immersive tool during the early design process.

Chapter II State of the art

Chapter II provides the state of the art of the three leading fields on which is constructed our research work. The Design Research field, the Human Science field as well as the Virtual Reality field are reviewed in this state of the art. This chapter is divided into four sections. The first section focuses

on the early design process, on its related theories and on the intermediate representations used during the design process (§2.2). The second section introduces to innovative and foreign methods with a particular take on subjectivity, product experience and its emotional semantic component (2.3). A review of the emotional and cognitive human models as well as their influence on the design practice is provided in the third section (§2.4). The state of the art is concluded by the synthesis of scientific elements contributing to the positioning of the study and the construction of an innovative and stimulating research question. This chapter finally leads to the formulation of research questions and the development of hypotheses in chapter III.

Chapter III Research question and hypothesis

Chapter III presents a research question and develops the hypotheses of this thesis. The core research question explored in this thesis is related to **how the early design process can be augmented by immersion in a spatial industrial design workflow** (§3.2). Two main hypotheses are explored: **Hypothesis 1** proposes to study if the Kansei related to a trend is modified by a spatial immersive experience of the moodboard (3.3.1); **Hypothesis 2** suggests that emotional activity during early design and the concepts which are the product of this activity are modified by a transposition of the traditional early design workflow into a spatial immersive workflow (3.3.2). This chapter encloses our core of the scientific direction of our research and is followed by the development of the empirical study in chapter IV.

Chapter IV Empirical study

Chapter IV relates the two experiments structured to validate or invalidate the specific hypotheses developed in Chapter III. EXP 1 is intended to identify the effect of immersion on the designer's experience of a moodboard. We proceed to a study involving sixteen product designers, based on the comparison of the immersive and traditional moodboards experience. In addition, the experiment is an opportunity to test a multidimensional model of the human experience based on cognitive, physiological and behavioral data (§4.2). The EXP2 aims at comparing a full length traditional and immersive early design process ranging from design brief to concept evaluation by the end-user via the inspiration and generation phases. This experiment purpose is to compare the emotional experience of the designers in traditional or in immersive condition, the quality of the sketched concept based on their source (Immersive/traditional). In addition this experiment studies if the *immersive condition* impacts the relation between the semantic-emotional intent of the designer and the end-user's semantic-emotional appreciation of the concepts (§4.3). Each sub-section includes results and their discussion. Finally, this chapter concludes on the validation of our hypotheses.

Chapter V Contribution of the study

Chapter V presents our key contributions based on the results from the empirical studies conducted in chapter IV. This chapter separately presents the academic contributions (§5.2) and the industrial contributions (§5.3). The academic contributions are composed of 4 models. One depicts the model of our framework for emotional activity and Kansei measurement (§5.2.1). The three others describe the emotional and semantic changes induced by immersion during early design (§5.2.2, §5.2.2.1, §5.2.2.2). The industrial contributions relate how the immersive workflow and the user experience measurement platform overtake the contemporary tools. In addition, this section provides a specification for the architecture of advanced early immersive experience. Finally, this chapter concludes by summarizing our contributions in the perspectives of both scientific and industrial communities.

Chapter VI Conclusions and perspectives

Chapter VI concludes by recapitulating the thesis (§0), and then closes by discussing the short, medium and long term perspectives of the hereby presented work (§6.2).

1. CHAPTER I - CONTEXT

1.6 INTRODUCTION TO THE RESEARCH CONTEXT

This chapter presents the main subject of this thesis and explains its industrial and academic context. Our research combines the domains of design research, virtual reality and human science. The Design is the activity to be optimized, Virtual Reality is the technological opportunity and Human Science provides interesting research methodologies. This context introduces how historically Virtual reality and computer aided designed have evolved separately for the last fifty years.

1.7 VIRTUAL REALITY CONTEXT

The present study is anchored in the *virtual reality*, human and technologic lineage. If the idea of potential realities appeared in ancient Greek with the philosopher Plato (424-348 AV J.C) in his *Allegory of the cave*, the first digital device created to immerse a conscience in a synthetized environment appeared in 1957 with the Sensorama machine patented in 1962 (United States Patent 0. 1. 3,050,870)(cf. Figure 2).

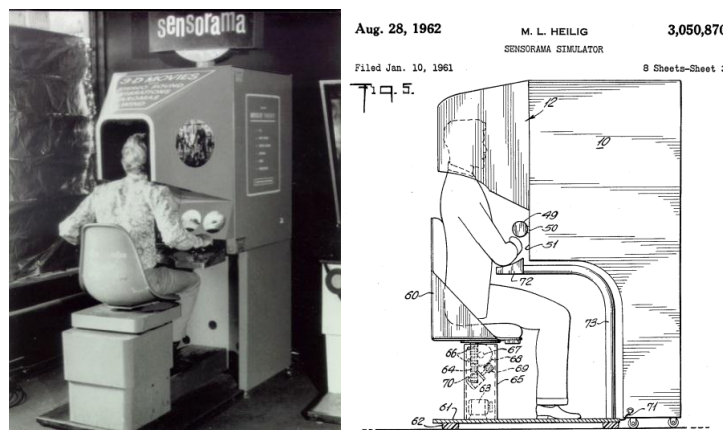


Figure 2 – Sensorama Machine by Morton Heilig

This device was intended to display stereoscopic motion pictures in a wide-angle view, to provide body tilting, to supply stereo sound, smell and other sensations like wind. This system has shown that a tight and deep interaction between human and machine was possible. Today, more than 50 years later, the technology has evolved, enabling the experience to thoroughly immerse a person in a virtual environment. Thanks to domains like the robotic or gaming and serious-gaming industries, immersive devices have flourished in different configuration and broadband democratized immersive experiences are appearing daily. However, in fifty years, the goal has not changed: to create an ecosystem in which the user is freely able to interact with digital data in a natural fashion.

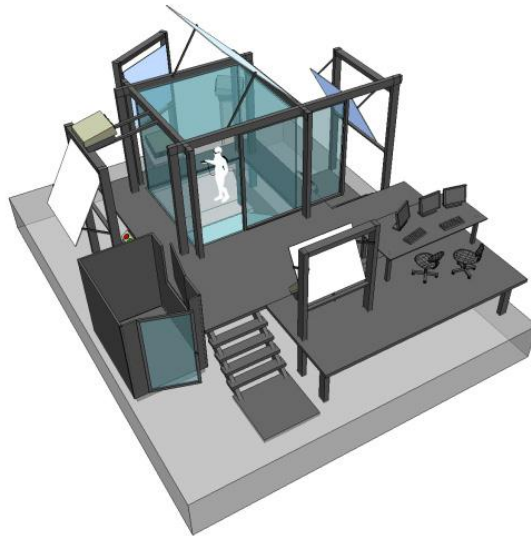


Figure 3 - Example of immersive cube (Electronic Visualization Laboratory)

Virtual reality has evolved from this point and now provides multisensory experiences in *display cube* (cf. Figure 3). The presence factor, the interactivity along with the graphic quality has increased with the development of new technologies and immersive techniques. Virtual reality has and still is intended to support broad activities. However, we will see that innovation in virtual reality and industrial design tools has evolved apart from one another.

The impacts of digitalization on design can be divided into two broad categories: changes in the value-chain from producer to consumer and changes in the work-processes resulting from the use of new tools. As a result, the conventional borders between product design, production and the user are beginning to merge.

1.8 COMPUTER AIDED DESIGN CONTEXT

Our study aims to understand the positive input induced by the introduction of immersive experience in a traditional activity of early industrial design. In that way we position our work in the Computer Aided Design science. *Sketchpad* (aka Robot Draftsman) is an innovative computer program written by Ivan Sutherland in 1963 as part of his PhD work at the Computer Laboratory of Cambridge University (cf. Figure 4). This system integrates part design ontologies such as automated constraints, product assembly hierarchy and other logical functions inspired from engineering work. Sketchpad is also a great resource in Human Computer Interface: it develops a natural interaction based on an analogy with writing, through the interaction with the *light pen* (stylus).

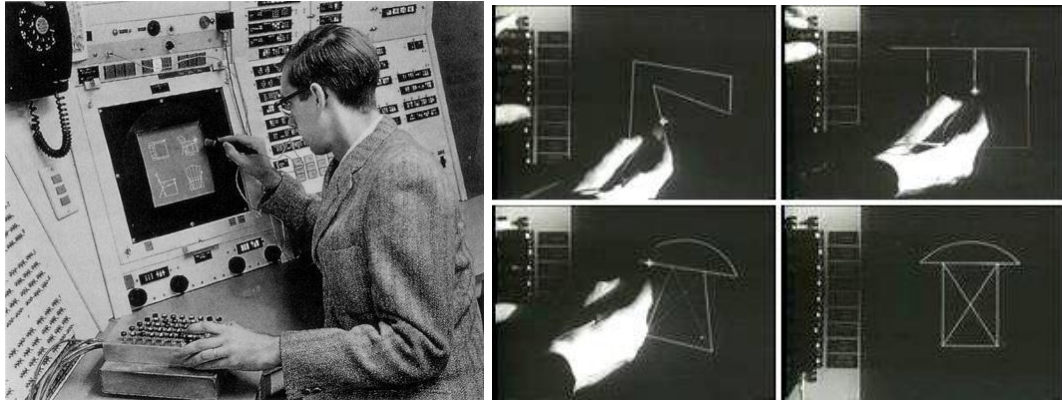


Figure 4 - Sketchpad Machine and light pen manipulation by Ivan Sutherland

At this time I. Sutherland already hints the hedonic and artistic opportunities offered by the experience. *“Sketchpad needs not be applied only to engineering drawings. The ability to put motion into the drawings suggests that it would be exciting to try making cartoons...”*. He predicts that his system could be multisensory, and also imagines that it would provide a good workspace to produce sound designs.

Since then Computer Aided Design follows a particular evolution: first it is used to aid manufacturing; later, for functional, engineering design. It is only in the last two decades that Computer Aided Design penetrates the aesthetic aspects of industrial design.

However, the techniques and features available in the industrial design oriented software are still grounded in engineering. They scarcely propose an innovative interface adapted to early design needs such as the creative and fast expression of design concepts.



Figure 5 - Example of common digital sketchpads year 2013

Fifty years separate I. Sutherland’s sketchpad from the contemporary sketchpad. We observe that graphics and calculation power have greatly improved. However, the interaction between the designer and his concept has not radically evolved. The contemporary tools, like the ancient, both

enable 2D sketching with a stylus and shortcut keys.

1.9 ACADEMIC CONTEXT

The evolution of technologies and uses render possible innovation both in virtual reality and in Computer Aided Design. Fifty years separate this research work from the discoveries of graphical sketching interfaces and immersive devices. However, industrial design still lacks the correct digital tools enabling the designer to operate fuzzy information during the early design process.

The NPDIL (New Product Development and Innovation Laboratory) is presently deploying a research program aimed to understand how early industrial design can be empowered by digital tools. This research work is part of a full digital early design workflow presently in development in the NPDIL (cf. Figure 6). The immersive early design experience presents itself along the given projects: KENSYS, TRENDS, DPRV, SKIPPI and GENIUS. All these tools are intended to support the design process from the idea to the product.

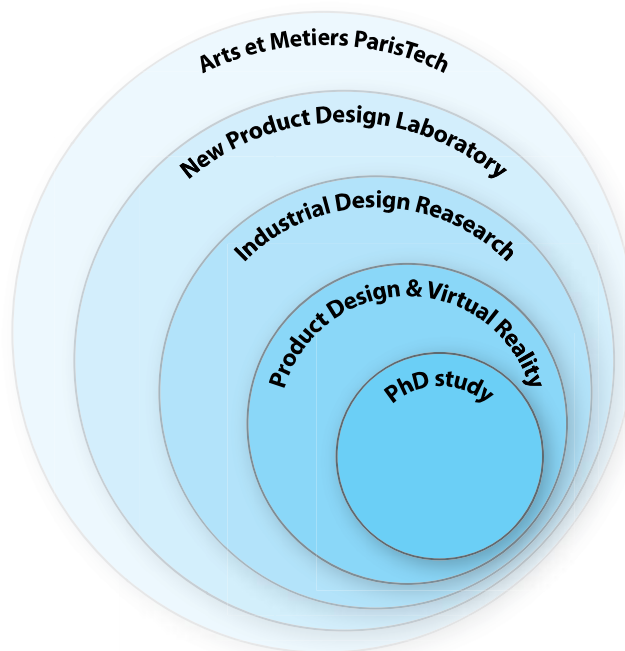


Figure 6 – Positioning this research study

2 CHAPTER II - STATE OF THE ART

2.1 INTRODUCTION TO THE STATE OF THE ART

In order to understand why virtual reality has not yet penetrated the early design activity we deploy an extensive study of design research, human science and virtual reality. Chapter II presents the designer's needs and contemporary practices. It also mentions opportunities provided by virtual reality technologies and understanding of the human mechanism that can be impacted (cf. Figure 7).

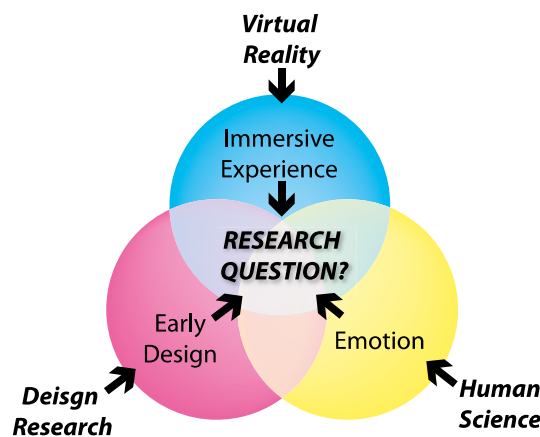


Figure 7 – Identifying an innovative research area

These three domains shape our research framework. The industrial design is the object to be optimized. The virtual reality is the studied technological opportunity and the human science provides the research methods to assess our theories. Going deeper into the link grouping those thematic we define Early Design, Immersive Experience and Emotion as being the focus of our research work.

Chapter II provides the state of the art of the three leading fields on which is constructed our research work. The early design field, the immersive experience field as well as the emotion field are reviewed in this state of the art. This chapter is divided into 4 sections. The first section focuses on the early design process, on its related theories and on the intermediate representations used during the design process. This section also introduce innovative and foreign methods with a particular take on subjectivity, product experience and its emotional semantic component (§2.2). The second section presents a review of the emotional human models as well as a presentation influence of emotions and subjectivity on the design practices (§2.3). The third section recounts the basis of the immersive experience as well as introduction to the concepts of spatialization and virtual reality techniques (§2.4).

The state of the art is concluded by the synthesis of scientific elements contributing to the positioning of the study and the construction of an innovative research question (§2.5). This chapter finally leads

to the formulation of the research question and the development of hypotheses in chapter III.

The next figure presents the synthesis of the state of the art (cf. Figure 8). The following statements come from the review of literature and list the common grounds between virtual reality, industrial design and human experience.

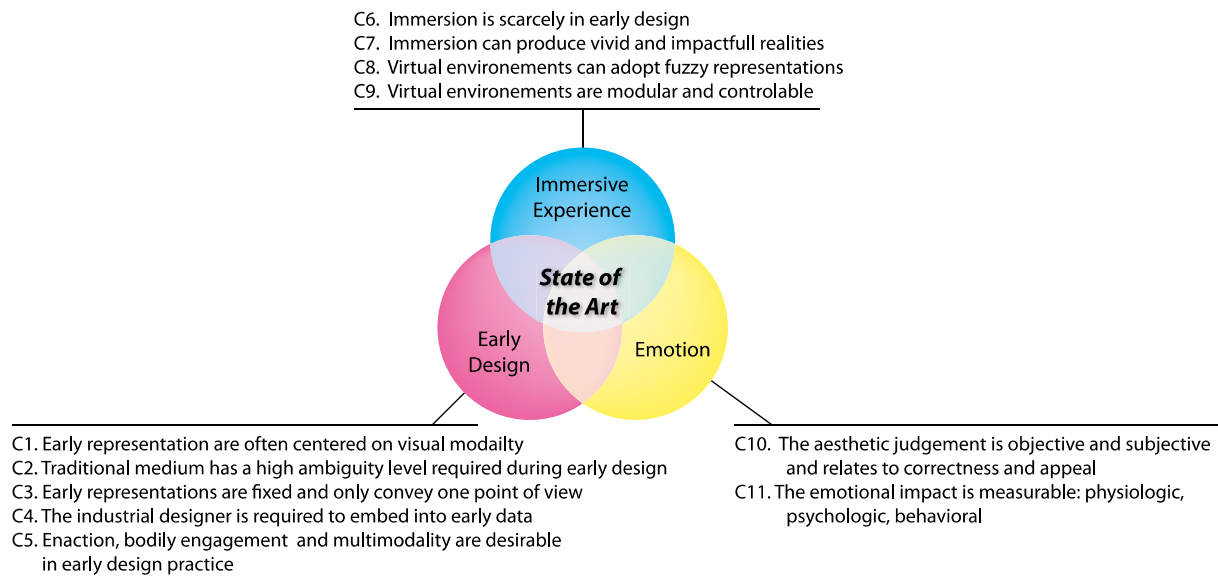


Figure 8 – State of the Art Statements

2.2 EARLY DESIGN

This section of the chapter II addresses the early design (cf. Figure 9).

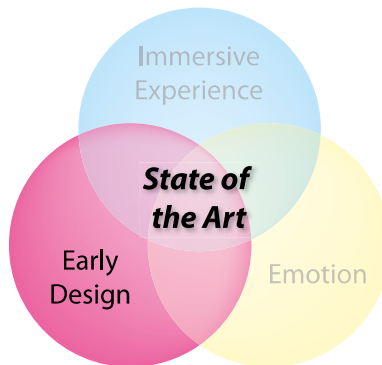


Figure 9 – Design component of the research work

It is divided in six sub-sections, including

- Reference models (§.2.2.1),
- The context of industrial design in a multidisciplinary process (§.2.2.2),
- A definition of the early design process (§.2.2.3),
- The theories of the early design process (§.2.2.3.3),
- The detailed intermediate representations used in industrial design (§.2.2.4),
- And finally a view of the industrial design evolution (§.2.2.5)

Next figure defines design with regard to its synonyms (cf. Figure 10). This lexical field shows the variety of aspects included in the semantic of design.

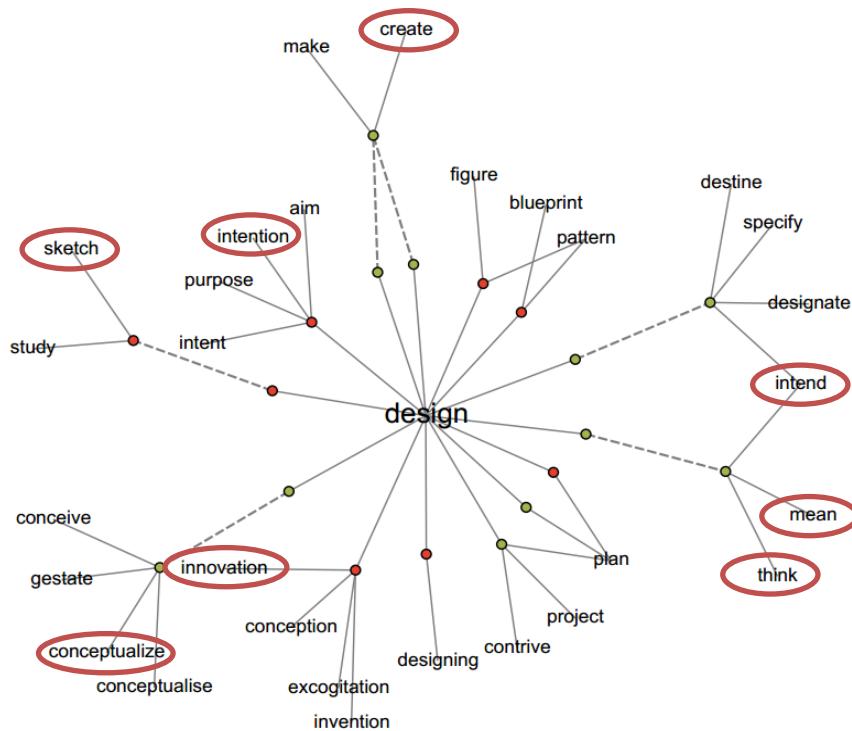


Figure 10 - Design defined by its synonym

In this semantic field, the marked aspects will be adopted as significant objects in our research study.

2.2.1 PRODUCT DESIGN PROCESS REFERENCE MODELS

Industrial design (Moholy-Nagy, 1947): *"To design is to organize a harmonious balance of material, processes in the most productive and economic way. All elements necessary to a function must be integrated in balanced and harmonious way. Thus design is not a mere problem of appearance but resides in the penetration and understanding of the products essence. The designer's task is complex and meticulous. As well as integrating technological, social and economic needs, he also takes in account biological needs or psycho-physiological impacts of materials, shapes, color, volume, space. The designer must perceive, at least from a biological point of view, the whole and the detail, the immediate and the outcome".*

The industrial designer is charged of integrating much different information in his product. According to L. Moholy-Nagy, in order to succeed in designing fitted objects, the designer must perfectly understand and manage the different levels contextualizing the object to design. He has to gather

from microscopic information, found in the domain of psycho-physiology to the macroscopic information, including the social context in which the design activity is embedded. Only a skilled design team is able to identify adequate features and to correctly address the needs of the end user. Fortunately the design team is equipped with a certain number of skills, methods and tools. These supports also assist the designer in formalizing a solution to the design problem. They constitute the solution and are deeply anchored in the resulting propositions of the designer. The tools of the designer not only impacts him in the way they act on but also in the way they think, perceive the world, and undertake the design problem (Kelly, 2003). For instance different types of architecture arise from different tools. Next figure presents two basic tools from two different cultures (cf. Figure 11). Invariably these give a different access to what sawing wood is.



Figure 11 - Tools as an embodied perception of the practice

However, common structure and skills emerge from design activities. Crucial skills like understanding the end-user's needs, expressing and representing ideas and anticipating their impact on the future end-user experience are fundamental to a good design process. In the same way, theoretical models of the process as a sequence composed of an exploration phase, followed by a generation phase, and a refinement phase commonly appear from different sources.

Design process: (Pahl & Beitz, 1984), (Christofol H. , 1995), (Yannou, 1998), (Ulrich & Eppinger, 2008), (Bouchard, 1997), (Hatchuel, 2002), (Petiot, 2007).

These models are synthesized in single model in § 2.2.3. They help us in defining the scope of our research with regard to a reference models we identify in the literature. Tools, skills, methods are far from being the only factors to influence the future product. The design process as we know it nowadays is a complex ecosystem with multiple facets. An object needs the expertise of different workmanship to reach the market. Next section introduces the different professions involved in product development.

2.2.2 INDUSTRIAL DESIGN IN A MULTIDISCIPLINARY TEAMWORK PROCESS

If the physicality of the object depends on the industrial designer's tools and decisions, the product is *shaped* by different stakeholders (Batill, 2000) (Simon, 1996). Design, marketing, engineering, ergonomics, psychology and production departments all coordinate in an effort to engender a product in a simple, fast and cheap fashion. The holistic product design process is not only the industrial design departments' responsibility. Thus it is important to keep in mind that compromises are made and decisions are taken by a group. In that way, it is necessary for early design tools to convey information in a universal language in order to share understanding of the design problems throughout the multidisciplinary team. In this study we will consider the industrial designer as the person enabling analysis and choices concerning the relationship between the product and the final user. This relationship will be detailed further in this paper (§2.2.5). (Quarante, 1994), (Buxton, 2007)

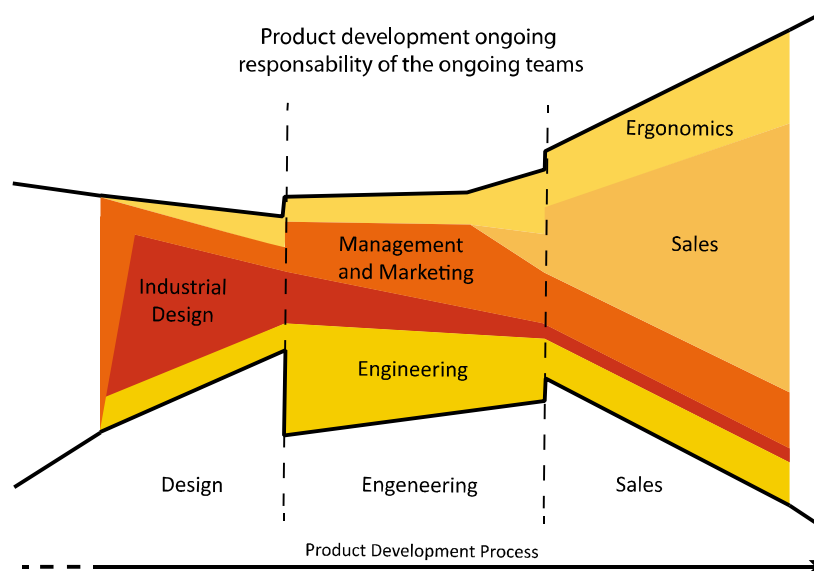


Figure 12 - Responsibility in product development (adapted from Bill Buxton)

Different teams and expertise take part in the complex product design process (cf. Figure 12). Industrial design, Engineering, Sales, Marketing, Management, Human Factors and many more take decisions and influence the final artifact. Timewise, the initial decisions made by the design team structure and anchor a great part the actions taken after the design process. This model testifies of the high impact of the design team on the final product's morphology and the user experience. This illustrates the importance of using adequate tools and methodologies during the early design phase. Our research goal is to ensure that the tools used during the early design phase are up-to-date and coherent with the designer's needs. The next paragraph proposes an overview of the design activity and specifies the time lapses we focus our study on.

2.2.3 THE EARLY DESIGN PROCESS

In this thesis, to refer to specific milestones in the product development process, we propose a synthesis of the models introduced in the previous *Product design process reference models* section (§2.2.1).

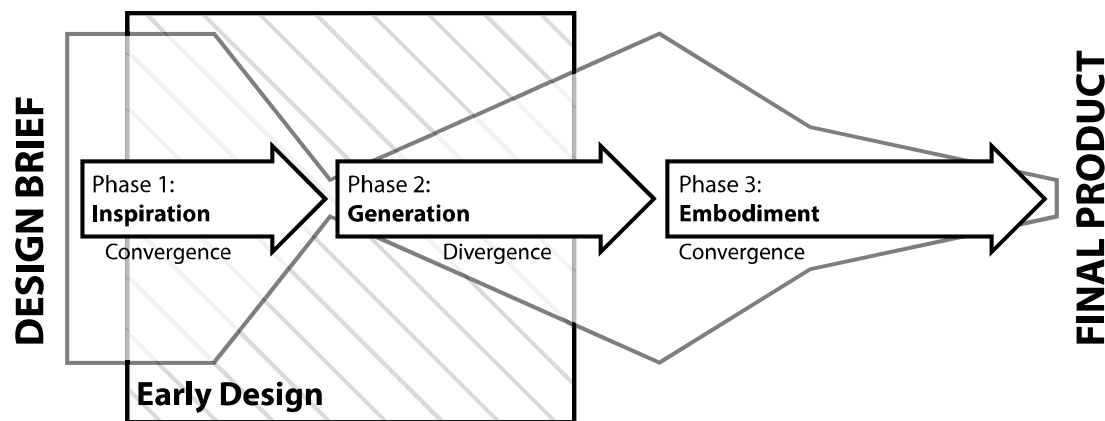


Figure 13 - Design process – Boundaries of early design

The industrial design process can be modeled by three major phases: the *inspiration phase*, the *generation phase* and the *embodiment phase*. (Bouchard C. , 2009) The inspiration phase withholds the explorative work aiming to understand the design problem and fertilize the design thinking with gathered inspiring information. The inspiration phase is followed by the generation phase (cf. Figure 13) in which the designer will construct formal representations of the product. The final phase is majorly composed of the selection of the best concept, its finalization, production and sale. We have chosen to focus our research on the early phases of the design process as they have a large impact on the nature of the final product. (cf. Figure 13). The next paragraphs will detail the early design activity and its functions. We first depict the inspiration phase (cf. §2.2.3.1), we then proceed to the description of the generation phase (cf. §2.2.3.2) and finish by presenting current theorizations of the early design process (cf. §2.2.3.3).

2.2.3.1 INSPIRATION PHASE: DATA GATHERING, CONSTRUCTION OF CONTEXTUAL KNOWLEDGE AND FORMALIZATION OF DESIGN GUIDELINES.

From a product point of view, we believe that the industrial design process can be modeled into three phases. A well designed product has been thought of and carefully studied to correctly fit the market. In order to do achieve this goal, the designer must first gather information from his environment to

inspire his creative act and match a given lifestyle, ambiance, atmosphere. (Caron G. , 2012). We call this data gathering the inspiration phase (cf. Figure 13 Phase1). This phase converges towards choices defining the first style guidelines. The general goal of this inspiration phase is to spot emerging trends. As the design briefs given by clients are too often insufficient to start an innovative product design (LCPI, 2010), this phase helps the industrial design team to construct their product with additional information.

Conjoint Trend Analysis is a strategic method for trend identification. It enables the designer to specify interesting trends by gathering sociological data and contemporary graphical representations (fashion; architectural; design...) (Bouchard, 2003). When the designer processes these pieces of information, he generates trend knowledge through experience, in an experimental process of learning by doing (Reigeluth, 1983). Once the trend is understood, it can be depicted on a moodboard and the project direction can then be assessed, with the collaboration of the designer's co-actors and product development stakeholders.

The revealed guidelines can be formalized into moodboards representing the different takes on the product style. The moodboard is then be used as inspiration material for the next phases of the design process. A moodboard is a harmonious graphical/semantic composition explaining the designer's take on the client requested universe, theme or ambiance. The moodboard has many inspiration functions such as: the definition of a design context, the trigger of idea generation, the structuring of anchors for mental representations. It also constitutes a formal vocabulary basis for communicating innovating ideas. (McDonagh , Goggin, & Squier, 2005). In addition, this early design process of formalizing the different takes on the product style will have a great impact on the success or fail of the designed product. The more the targeted trend is understood, the more the designer will benefit from the information and will be accurate and creative in its work. Creating a moodboard is not systematic. The synthesis work and stylistic choices can be informally executed by the design team. However, it is argued that capitalizing the gathered information through formalized representation appears as advantageous to the design project (Setchi & Bouchard, 2010). As the decisions taken during such early design activities represent most of what the product will be, the tools used during these phases must be highly effective. A moodboard can be considered as the disembodied beta version of the product that specifically addresses the style by design attribute combination. In that way the moodboard is an intermediate representation of the final product. As eighty percent of the design process are determined during the front end, preliminary analysis and evaluations are the bottleneck of the design process. The stylistic decisions taken during the inspiration phase (cf. Figure 13 Phase1) freeze a certain number of the designed product parameters.

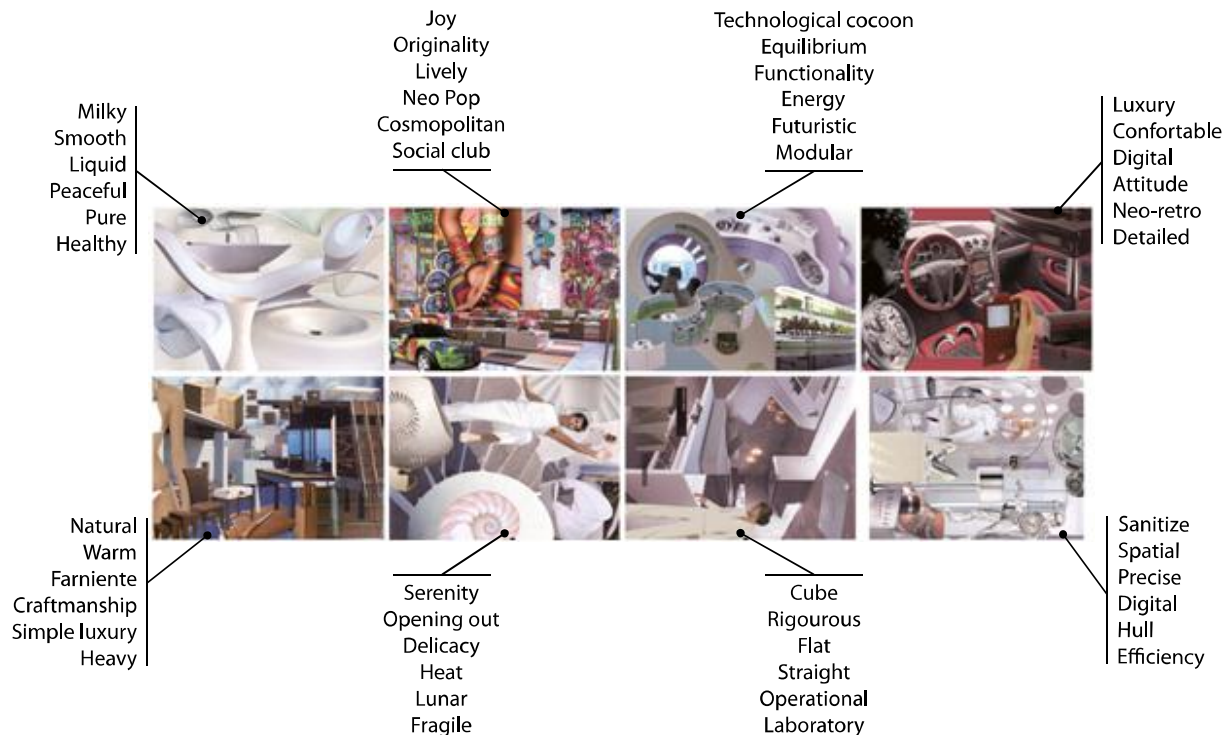


Figure 14 - Eight trends identified through the Conjoint Trend Analysis and, their associated semantic fields and moodboards (Bouchard / RIEUF, 2010)

The general goal of this inspiration phase (1) is to discover trails and spot emerging trends. It also helps providing a support for the industrial design team to project itself in the represented style, thus enabling its evaluation and the construction of new knowledge on the product design evolution. The next paragraph depicts how the lack of information necessary to build a concept is burdensome, given the abstract nature of the parameters the designer is compelled to work with.

The design activity takes its references in latent data either provided by the brief, the customer, the designer's immediate environment or indirectly gathered from the analysis of the end-user and the targeted markets. The designer has to synthesize this data and operate with it before he is able to design concepts. Technological opportunities, marketing prospects, ergonomic studies, psychological theories, cultural codes and aesthetic factors supply the designer's research towards his goals. Industrial design is an activity which aims to characterize an object with regard to parameters such as originality, universality, use, economic value, ecological value, integrated technologies, semiotics, cultural and social inlaying, the overall experience it provokes and the needs for its industrialization. (Beringer, 2012). Therefore the designer manipulates a complex set of interrelated data (cf. Figure 15). This complexity can only be managed with the right tools. It provides support for the designer to articulate this information, crystalize it and evaluate a product design trail.

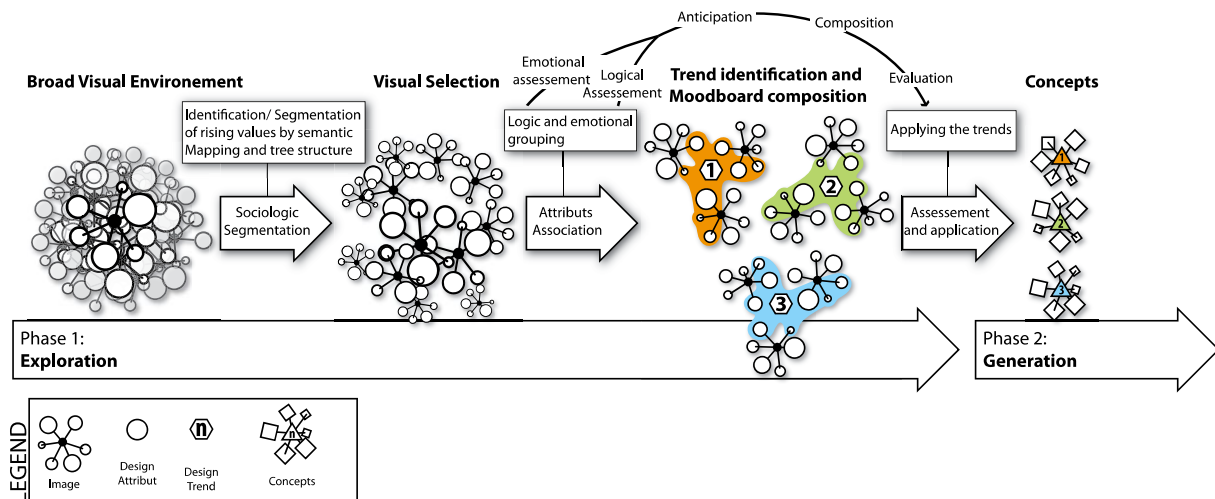


Figure 15 – Detailed attribute transfer from inspiration to concept

The designer gathers sufficient information in order to identify the core of the design problem. When he has composed the major guidelines for his project, he is able to engage in the generation phase (cf. Figure 15 Phase2). The next paragraph will display a descriptive model of the generation phase as well as the key theories related to the generation phase.

2.2.3.2 GENERATION PHASE: EXTERNALIZATION PROCESS AND NATURE OF THE RESULTING INTERMEDIATE REPRESENTATIONS.

The *generation phase* follows the inspiration phase. It is based on the contextual knowledge generated during the inspiration phase. If the inspiration phase is a process converging towards the proposition of design guidelines, the generation phase however, is divergent. It aims to explore the different acceptable solutions to the design problem. During the generation phase, the designer transforms the data collected in the inspiration phases into tangible design solutions by means of representations. (cf. Figure 16).

The generation phase has multiple goals: to enlarge the bandwidth of concept possibilities, and stimulate creative outcomes, to produce physical representation of the product in order to assess feasibility and spatial coherence, to assess the appeal of a given solution as well as to communicate ideas within the design team, to stakeholders or to end-user. Traditionally, the pen and the paper are the first tool used to bring concepts from the imaginary to the tangible space. In this next paragraph we explain how the generation phase is articulated. We first explain the function of the generation phase regarding the overall design process.

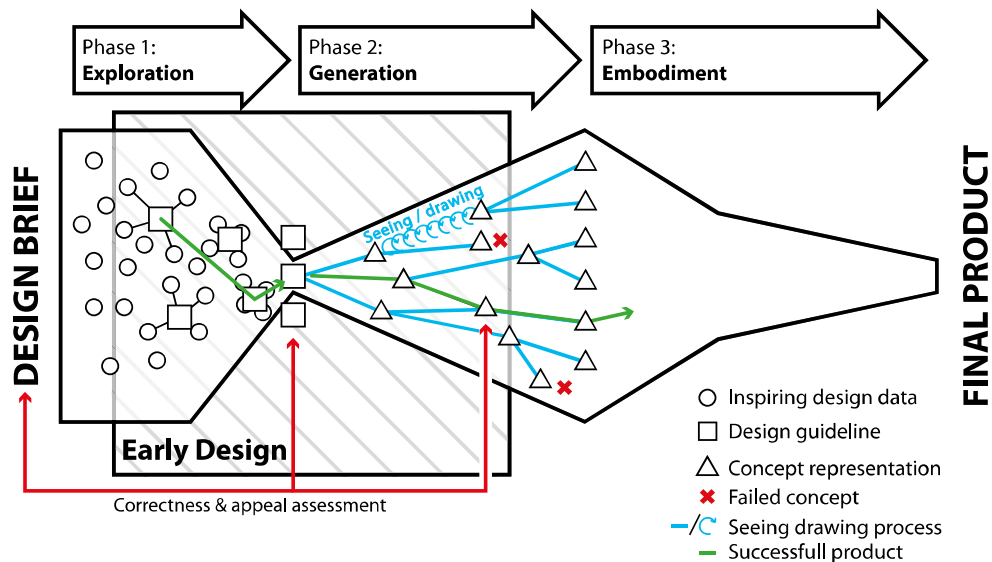


Figure 16 - Detailed Inspiration and generation process

In opposition to the inspiration representation which defines the aimed feel for this product, the generation representations embody the future product,

"When sketching snapshots or aspects of possible futures (such as future products), the designer is not merely copying images from her inner eye. The drawings are micro-experiments that respond with insights into strengths, weaknesses and possible changes in a tight loop of thinking that involves the hand, the senses and the mind. [...] If a particular external representation serves to engage the designer in a conversation about the details and implications of a not-yet-finalized idea [...] then it is a sketch. It could be anything from a napkin drawing to a piece of programming code, what matters is the purpose and intention" (Löwgren, 2013).

The design practice involves thinking and feeling through sketching and other tangible representations. In this citation, Jonas Löwgren refers to the process of sketching as a *conversation* between the sketched concept and the industrial designer. It is also a means for product designer to convert his ideas into tangible concepts. By transposing the design concept from a mental state to the sketch, the industrial designers narrow their concept to a possible shape and force the confrontation between the mental and the physical reality. In this document, we will refer to this conversion as the *externalization process*. The outcome of the externalization process during the generative phase will be named *intermediate representations*, as they only embody part of the parameters that compose the final product. It is common for the designer to refer to a representation of his ideas in order to work with/on them. The externalized concepts are used to communicate, negotiate, explain ideas to coworkers or clients and result in the sharing of common knowledge of the process. (Vinck, 2011). Representations are the externalized traces of the design thinking and are used for product

evaluation, to identify defects, find alternative solutions, estimate fabrication time/costs and stimulate designer to designer or designer to client dialogue (Goebel, 2001). They are here to simulate essential product properties and are used from the first ideas to the final artifact rendering. During the design process, hypotheses are made and evaluated by means of intermediate representations.

A significant part of early representations are hyper-centered on visual evaluation. As the fuzzy front end of design goes, hypotheses made in this phase concern many of the sensorial modalities (Bassereau J.-F. , 2001) (Bassereau J.-F. , 2009) (Guenand, Gapenne , Lenay, Maillet, Stewart, & Thouvenin, 2007-08) It is difficult for a designer to evaluate future products properties when unable to appreciate them under their multimodal form (Kadri, 2007). A design defect can even only be detected once the final prototype is rendered and subsequently release additional funds or mobilize a design team for an undetermined time. Thus it is crucial to identify any possible defect or promising designs through early representation as soon as possible to ensure a successful and competitive product. The design process is dotted with intermediate representations to help evaluation and decision making. However, these representations have limitations and embody only part of the design issues. The more the representation simulates the final product, the better the represented solution can be evaluated and the better the strategic decisions concerning the object design can be trusted (Kadri, 2007). Paradoxically, these representations still need to be ambiguous (fuzzy) so that they leave an open space for design thinking. As these representations are supports for inspiration, they are required to be unfinished and with a certain degree of abstraction (Buxton, Sketching user experience, 2007). To sum up, a good design intermediate representation has a good balance between the information it conveys and the questions it asks according to its time framing in the design process. *Concept & Knowledge* theory identifies these spaces as conceptual space (questions, expands) and knowledge space (answers, sums up) (Hatchuel & Weil, 2009). Representations found in the early design process are more of a conceptual nature, in opposition to late design representations which are closer to proposals.

The overall divergence of the generation process is due to the fact that through sketching, the industrial designer composes multiple hypotheses regarding the shape, color and texture of the future object. The industrial designer's workflow can be modeled by a tree structure (cf. Figure 16). In order to produce, the designer recalls his tacit knowledge to support his mastery of the tool. As explained in preceding paragraphs (§2.2.1 p. 24) the intermediate representations are the designer's enactive access to the design solution space. To summarize, intermediate representations are a formal hypothesis generation and evaluation tool. They enable the identification of defects and

assets as well as open the dialogue over design attributes. In the contemporary design process, the intermediate representations are highly visual. Timewise, the more the design process advances the more precisely design attributes are represented. During the crucial phase of early design, working on a product implies a media that allows a good apprehension of the emotional aspect inherent to design and that enables the representation to feel vivid or and as a part of the designer's world.

The externalization process is often explained using the problem solving theories, regarding the design brief as a problem and the product as its solution. Next section details classic but advanced theories on design as a problem solving activity.

2.2.3.3 DESIGN THEORIES

The intrinsic necessity for a designer to externalize tangible concepts has raised question on the relationship between knowledge and intermediate representation. The upcoming paragraphs detail 4 theories which explain the relationship between the designer and his tool (cf. §2.2.1).

- **The *Gestalt* theory**

Historically the Gestaltists are the first theoreticians to consider the design as a problem solving activity. In German, « Gestalt » means « shape ». The Gestalt theory comes from the psychological model of complex systems. From these studies, a model of in which the human perception is first founded and design principles are extracted. For the Gestaltists, the design process is divided in four steps (cf. Figure 17). During the *preparation*, the designer identifies the problem and understands that there is a difference between the actual state of his problem and the aimed state. The *incubation* state is a relief of the conscious activity when trying to solve the problem. The *insight* is the step during which the designer is trying to analyses the problem and finds a valid solution answering the problem. The final step of this theory is the *assessment*, during which the designer verifies that the solution corresponds to the goal fixed during the preparation phase. (Westheimer, 1999). Industrial design as a problem solving activity has enabled the modeling of the decision making process based on graphical representations (Englisch, Sachse, & Uhlmann, 2008). This model represents the design process as an iterative process, and accordingly it can be figured as a cycle. This cycle is composed of the mental anticipation of a new products' state based on previous evaluations and on the operations that could invoke this new status.

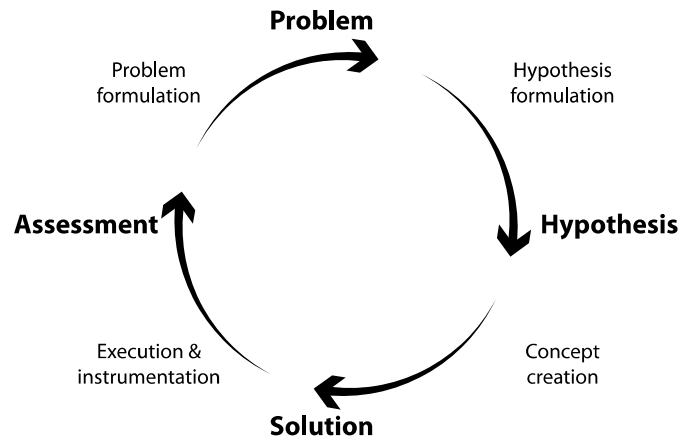


Figure 17 - Design Hypothesis formulation and correction cycle (Christofol, 1995) Actualiser refs

At first the industrial designer identifies the design problem. He mentally formulates his hypothesis and externalizes it through concept generation. Once the solutions are externalized, the designer is able to assess his work and to modify his vision of the problem. This cycle develops onward until the acquisition of a satisfying solution.

- **The *concept & knowledge* theory**
- The *concept & knowledge* theory identifies two spaces in the product design development. (Hatchuel & Weil, 2009). The conceptual space (questions, expands) represents the space encapsulating the concepts: the propositions without a logical and finished status. The knowledge space answers, sums up, however, it holds the propositions with a logical and finished status. This theory explains design by a series of operations (expansion, disjunction, conjunction) linking these two spaces and resulting in the construction of new concepts and new knowledge. Once again this theory evokes the conversation between the sketched concept and the industrial designer
- **The *seeing/drawing/seeing* theory**

Schön et Wiggins (Schön & Wiggins, 1992) introduce the idea that visual design representation in industrial design have a specific purpose linked to visual thinking. It is frequently argued that the industrial designer engages dialogue with himself by means of sketch (cf. Figure 18).

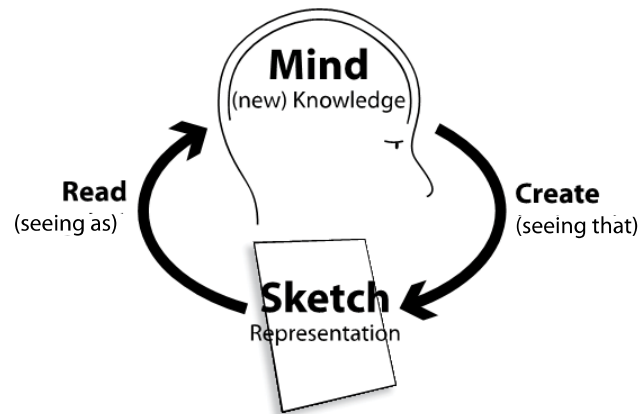


Figure 18 - The "seeing-drawing-seeing" process in design

This dialogue model represents the design activity as a loop during which the designer externalizes his ideas through the creation of a sketch (seeing that), and then assesses the result by reflecting on the evolution of his sketch (seeing as). (Schön & Wiggins, 1992) (Bucciarelli, 2002) (Dorta T. , 2008)

As Gestalt theory presents in the *incubation phase*, an input from imported sources (outside the design processes loops). This phenomenon is considered as beneficial to the design activity. In reference to the model presented in Figure 15, this imported source reveals the functioning of inspiration. Tools like moodboards fulfill this function with efficiency. In conclusion, the reviewed theories show that the designer needs a medium both to externalize solutions to the design problem, and to internalize knowledge on the said problem. Thus intermediate representations are necessary to the good development of the design process. The next section presents intermediate representations in their different manifestations.

2.2.4 INTERMEDIATE REPRESENTATIONS

This section gathers the traditional and innovative representations which can be produced and used during the design process. This review helps in positioning our work and identifying the representational environment in which the designer's activity takes place. This section is composed of two subsections. The first one depicts the traditional early representations with regard to the early design process in which they are used. The second one identifies innovative representations used in early design.

The object of a representation and its support are merged (Heidegger, 1927) .Any medium can be used to create an intermediate representation of a product. One might prefer charcoal to origami but both can support the externalization of a concept and assist in the expression of a take on the future

product. However, some classical representations are commonly used during the design process.

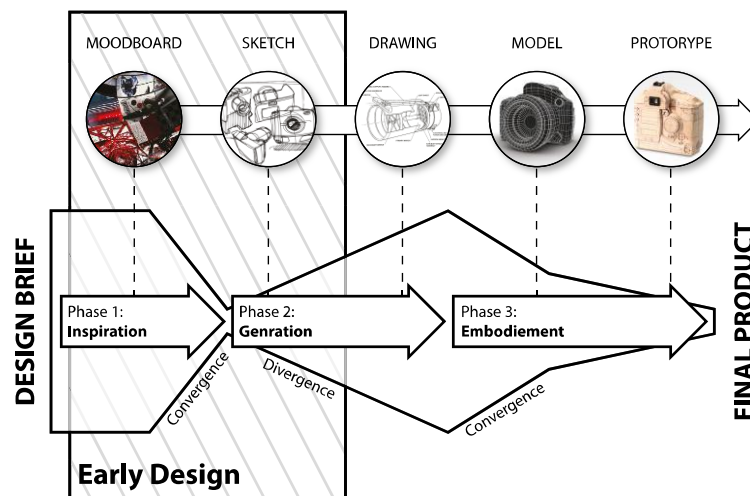


Figure 19 - Intermediate traditional representations along the sign process

The next paragraphs will briefly expose the different tools available to construct a design problem, inspire design guidelines and generate concepts. (cf. Figure 19).

2.2.4.1 INSPIRATION PHASE RELATED EARLY REPRESENTATIONS

We first describe the supports produced and used during the inspiration phase. Their function is to help the industrial designer to structure the design problem. These tools are often based on data gathering techniques.

- **Product Benchmark:** Benchmarking is the analysis of existing product situated on the same or on close market segments. It enables the industrial designer to understand the industrial & commercial landscape. It also helps in the identification of innovation gaps and technological and process opportunities.
- **End-user analysis:** This technique helps the design team model their end-user and understand their opinions, desires and expectations. Qualifying the needs of the end-user enriches the knowledge in order to the design task to be better executed. This technique uses product or brand centered surveys, interviews and even in some particular context, web based analysis and physiological analysis.
- **Sociological and ethnographical analysis:** This analysis is based on the understanding of the social context and the values of a country, social group or market. This can enable the anticipation of changes in the product development setting. These studies are either based on massive surveying or on an objective day to day observation of a population.
- **Visual press analysis:** By listing and categorizing data from up to date press information, the

industrial design team can identify growing trends and classify low level data such as color palettes, textures, materials, and seductive shapes, but also processes and high level data such as ambiance, lifestyle, dynamics and aesthetics.

- **Moodboard:** The moodboard is the industrial designer's tool to synthesize the data collected during the inspiration phase. It is composed of a collage displaying a set of color, textures and shapes but it also captures and relays the social context of the user, his lifestyle, cultural affiliation, values and the different data gathered in the prior analysis. Moodboards are used as references for the generative phase.

The prior function of the inspiration phase is to complement the brief and to set goals and guidelines. Many of the above techniques are used to enlarge and comprehend the context of the product to be designed. This is particularly essential when trying to precisely define the end-user/product relationship. With the use of such techniques, the decisions taken in oncoming phases of design are based on substantial project knowledge. (McDonagh , Goggin, & Squier, 2005) The moodboards are the tangible output of this inspiration phase. Even though moodboards present a rough and uncertain cluster of design information, they are still the result of decisions and are already a very representation of the final product.

2.2.4.2 GENERATION PHASE RELATED EARLY REPRESENTATIONS

Once the inspiration phase is executed, the design problem clarified and the design guidelines set, the industrial designer can take a stance and propose concepts with defined lines. During this phase he will produce a large number of propositions. His production extends his vision of the conceptual space in which he wants his future product to be in. I also narrows the possible outcome through timewise operated decisions. Though we have found that some designers use wire netting, origami, or foam board... to generate *quick-and-dirty* concepts, these are unconventional techniques. Here are some of the traditional means used to externalize concepts:

- **Sketching:** The most archetypal tool of design has been sketching for centuries

Sketch types	Function
Design sketch	enables design thinking and is coming from design thinking
Memory sketch	enables the industrial designer to capture and restore his ideas
Presentation drawing	can be deciphered by a broad public and understood by the untrained eye
Technical drawing	encrypts the data necessary to the production of a product an object
Description drawing	depicts a systems' function, an interaction or any other timewise phenomenon

Tableau 1 - Types of sketches (Lawson, 1994) (Powell, 1990) (Brown, 2003) (Buxton, Sketching user experience, 2007)

- **Clay:** The clay model is a formal representation of the finished product. It enables the test and

evaluation of formal solutions. If the wooden and foam core of the model is not modifiable, a medium range around the surface can be easily reshaped. Clay modeling activity is enactive and refers to the designer's tacit knowledge (Schön & Wiggins, 1992). This enables quick iteration and the use of trials and errors method in an advanced state of the industrial representations. This type of model gives access to a complete shape with a great level of detail. In addition to validating the formal features of the future product, some models are color coated to confirm the harmony of shape, color and surface aspect. The clay model enables a visual as well as a high level judgment of the product.

- **CAD:** Computer Aided Design tools are digital three-dimensional tools enabling shape editing through parametric interaction. Industrial design software forces the exact characterization of shape, which allows communication between the industrial, engineering and production teams (Girard, 2003). This modular approach of shape separates body engagement from shape generation. Unlike sketching with traditional tools, computer aided design does not integrate gestural based shaping. In computer Computer Aided Design approaches, shape is the result of a set of numbers computed predetermined functions. There are existing software approaching digital shape work through simulated clay modeling, yet these representations have a diminished quality due to the fact that they are scarcely used with haptic interaction. Using a digital representation of the product also enables material rendering and light simulation. (Bouvier, 2009). One of the flaws of this tool is that the three dimensions representation is displayed on a two dimension screen. This forces a distortion of the proportions of the object which can result in errors in the shaping process.
- **VRAID:** Virtual Reality Aided Industrial Design techniques are already used in industrially leading corporations (PSA, 2004). Nowadays, the major function of VR is to validate 1:1 scale products by real-time interaction, and replace real models to reduce the projects time and cost. Further than validation, VR is also used as a virtual support for concept generation in engineering design. The more the activity encloses early stage design, like conceptual design, the less VR tools are developed and used. A few projects have been exploring three dimensional sketching or virtual subjectivity based design: Sketch Furniture (Front Design, 2007), (Mat, 2008), (Shibata & Miyakawa, 2003), (Bae, Balakrishnan, & Singh, 2009). These approaches tend to explore mechanisms close to the early stages of industrial design. Nevertheless, we have observed that virtual reality is not very implanted in the first steps of industrial design. Woelfel (Woelfel, Krzywinski, & Drechsel, 2010) explains this absence in the fuzzy front end of the new product development by comparing the fuzziness of sketching and the geometrical strictness of virtual model data (Buxton, Sketching user experience, 2007).

The necessity of ambiguous non-restrictive representation techniques in the early phases can be the cause of the virtual technologies rejection. Fuchs reminds us that virtual reality techniques can be used to emulate aspects of the real world, but that it can also depict a symbolic unrealistic world. *“Virtual reality has the potential to go farther than copy [...] and to generate imaginary environments out of an artist or a science fiction writer. In this case the environment is not necessarily a simulation of the real world, particularly concerning virtual entities laws”* (Fuchs & Moreau, 2006). A numeric design process can also create a dependency to computerized system and reduce abstraction capacities. (Dorta T. , 2009) If simulation is a cheap and quick way to evaluate a product design, it is fundamentally different from reality. The perception of an object can therefore be distorted. For this reason virtual reality cannot be the only representation type used during the new product development (Kadri, 2007). Although the use of virtual reality techniques occurs scarcely in the early steps of the design process, it seems that the technological possibilities could enable preliminary design studies. The sensorial interaction power necessary to an early industrial product evaluation are available. And the possibilities of keeping the fuzziness required in premature representation can be obtained in three-dimensional interactive environments.

The externalization process, like most of the design process, is consequently based on a co-construction of the problem and of the solution. The externalized propositions help the designer reflect and rethink the design problem but in opposition also help to converge towards a unique finite solution. The externalization process can be modeled by a set of micro successive conceptual convergence/divergence phase. The sequence is analogous to a discussion or debate progressively directed toward the final proposition. The available traditional techniques are subjected to a proportional relationship. The more the externalized representation simulates the final product, the more it is costly and time consuming (Baccino, 2005).

2.2.4.3 INNOVATIVE EARLY REPRESENTATION

After looking at the early design landscape, we can see that few innovative tools have radically modified the industrial designer's workflow. Still we have identified interesting attempts to propose different approaches for the inspiration and generation phases of design. For instance, moodboards composed with small clips of video/sound and indirectly representing the brand and its products have been used to communicate high-level information during the early design process (Mougenot, 2007). A multisensory experience of the moodboards has been developed offering the industrial designer a

better immersion in the inspiration space it proposes (Gentner, 2011). A tool using real objects and capturing devices to explore and compose has also been built (Wendrich, 2009) to create live inspiration boards. In addition, the *Front Design* agency has proposed a system called sketch furniture. This system is designed to draw in the three dimensional space. However, the designers do not have visual feedback and must use their imagination to recall their past strokes (Bae, Balakrishnan, & Singh, 2009). Other researchers are exploring how early design could be assisted by automatically generated contours (Kim, 2011). These innovative representations often open towards innovative methods and disrupt the conventional processes of design. The next section presents the predominant design methodologies since the 20th century.

2.2.5 EVOLUTION OF THE INDUSTRIAL DESIGN PRACTICE

This section relates the different types of design methods. Each of the identified method is defined by its singularities. For a long time the most fundamental aspect of design has been the study and selection of the right shape, color and texture for a harmonious result. A correct design would balance the physicality and the function of the product so that both fit the end-users desire. (Droste, 2002) Some recent work have explored the *end-users desire* and shown that a functionalist vision of the relationship linking object and end-user is too simplistic. Must form only follow function, or must an object not only be considered as a mean to a practical goal? It is now admitted that a more complex interaction exists between object and human being. Since the early 1980s' functionalism is gradually being replaced by a more sensorial, emotional and hedonic take on product design (Childs T. , 2007). The new considerations are more of an abstract nature. Nowadays researchers have been developping methodologies on how to design a human/object interaction (Ludden, Schifferstein, & Hekkert, 2008), emotional impact (Norman D. , 2002) (Nagamachi M. , 2002), sensorial design (Bonnamy, 2009). Here is a description of the methodologies developing design for this complex human/object relationship.

Method
Sensorial Design
Emotional Design
Interaction Design
Affective Computing
Experience Design

Tableau 2 – Design methods synthesis ((Kim, Modeling cognitive and affective processes of designers in the early stages of design: mental categorization of information processing, 2011) (Ocnarescu, 2012) (Bongard-Blanchy, 2013))

Sensorial Design: Sensorial design is the mastery of the perceived aspects of a product. It is based on the principle that sensations can be specified, predicted, induced and measured. Sensorial design is based on sensorial analysis of design probes or existing products. These analyses use tools, protocols, trials, but also trained experts able to render systematic evaluations of a given stimulus. The goal of this activity is to increase the perceived quality of a product and create sensorial useful cues in the product.

Emotional Design: Emotional design has neuro-scientific breakthrough for background. The fact that emotion is such a volatile concept has kept the designer from instrumentalizing it for a long time. With the development of measurement and prescriptive methods, emotional design has proven to be a rewarding approach. The goal of emotional design is to define the users' pleasure and develop a product that induces and sustains the desired emotions whether it is provoked by the act of buying, the use or the simple fact of owning the designed object (Jordan, 2000). In the following research we consider emotion as a response to a stimulus due to a change in a person's environment. The emotion is characterized by a multidimensional model: *psychological*, *physiological* and *behavioral*.

Interaction (Tangible) Design: Once again this design activity is human centered. Interaction design is the study of the reciprocal relationship between the user and the system. This practice appeared with the emergence of the digital products, but it has produced theories relevant for all tangible objects. The major objective of interaction design is to design a compelling relation between the human, his knowledge, the world and its information (Moggridge, 2007). The interaction designer creates a system in which the end-user is able to act on an object and retroactively feel the response of the object. This interactive cycle is designed so that the user can build knowledge and construct interaction schemes through the perceived invariants (Verplank, 2007). The practitioners of interaction design have chosen to add time and behavior as a central parameter in the human-object relationship.

Affective computing: This computing activity relates to, arises from, or deliberately influences emotions. Computational systems are endowed with the ability to sense, recognize, trigger and understand human emotions, together with the skills to respond in an intelligent, sensitive, and respectful manner toward the user and his emotions. (Picard R. , 2007)

Experience Design: Experience design is a methodology which aims to understand and create engaging experiences. (Roto, 2013). *An experience is a person's perceptions and responses that result from the use or anticipated use of a product, system or service* – (Normalization ISO 9241-210 (2010)). It seems hard to measure an experience and even more difficult to anticipate the experience induced

by a product (Ocnarescu, 2012). *Although one might try hard as a designer, an experience cannot be guaranteed [...] experience emerges from a variety of aspects, many of them beyond the control of design... some outstanding experiences may come without careful crafting...* (Hassenzahl & Carroll, 2005). Experience design is yet to be improved but already frameworks have emerged and have proven to be successful (Ludden, Schifferstein, & Hekkert, 2008).

The evolution of the industrial design process has enlarged the industrial designers work boundaries. The more we understand the complexity of the human/object relationship, the more the design task is rendered complex. Function, sensation, emotion, interaction, experience must be integrated and thought of individually and as a whole from the start of the design process. Industrial design now calls for the industrial designer to understand the end-user in very profound ways (emotions, values, aspirations). This new challenge requires innovative tools with which it is easy for the designer to connect with his end-users and through which he is able to imagine and design this complex relationship.

The previously listed methods originate from Europe and North America. We can see how these methods divert from the initially functionalist design. Our research leads us to discovering an innovative and original foreign method. This method is presented in the next section.

2.2.5.1 KANSEI DESIGN, A HOLISTIC APPROACH TO THE HUMAN/OBJECT LINK

A promising methodology created in Japan mentions an original way of seeing user-centered design. In this particular vision, the link between a human being and an object is advanced in terms of designing for inducing an emotional impact. The related approach is called *Kansei*. We will now define this term, expose the different methodologies of Kansei design and show how these methods could help us enhance the design inspiration phases. The term Kansei (or Kansai) has been introduced from Japanese culture. As it has no direct translation, contemporary researches have been made on the term signification itself. Here are a few of the most referred to definitions:

- Kansei is to be understood as a global and immediate perception of a person and its psycho-physiological impact (emotion, sensation...). In other words Kansei is the global feeling one has once he has perceived an object or environment through his sensory system. (Harada, 1998)
- Kansei is the sensory and cognitive effect of an object, environment or situation on a person.

(Shütte, 2006)

- Kansei is sensibility, signification, feelings, aesthetics, emotion, affect and intuition (Nagamachi M. , 2002)



Figure 20 - Kansei: a holistic approach of the human/product relationship (Akira Arada / Shemgttee Lee)

In this research work, we consider Kansei as being a holistic term which withholds the complex link expressed in Figure 20. The usefulness of the term Kansei lies in the holistic approach of a human/object relationship (cf. Figure 20). The duality between Chisei and Kansei evokes the description of the aesthetic judgment by (Uhlmann, 2007): as the correctness of a product depends more of a Chisei matter (cf. Figure 21) the appeal of a product is closer to the Kansei domain.

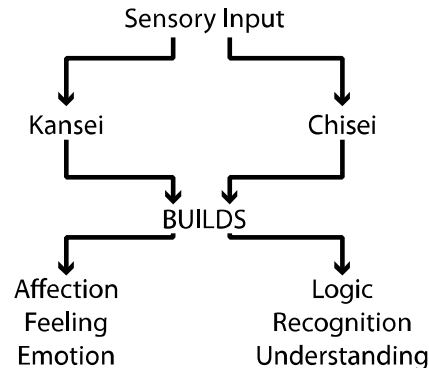


Figure 21 - Kansei & Chisei

Kansei design is a methodology that centers product design on Kansei analysis. Kansei design connects specific populations' emotional needs with precise products properties and maps how they respond to one another in order to detect and predict impactful design parameters. *Kansei can be analogue or digital depending on its type: I to VI* ((Matsubara & Nagamachi, 1995)). At first the connection between needs and design properties was made manually by organizing emotional needs into a tree form diagram and other similar mapping tools (type I). Evolution of Artificial Intelligence enabled to process the Kansei related information via mathematical statistical tools (type II). These digital tools enabled designers to predict the emotional impact of a given product on a given

population (type III). Virtual Kansei design replaces real products by virtual mock-ups and immersive environments combined with standard data collection methods (type V). The research presented in this thesis is mainly based on this last Kansei type. Recently Kansei has been used over the web 2.0, enabling distant collaboration and concurrent engineering. Kansei information databases are now connected to the web and are auto fed by their users. The more people use the database, the more information is harvested from potential users (Assouly, 2007).

In time, in a relationship of a given product to a given population, Kansei evolves. In fact, the temporal and material context of a user and his product has a direct impact on Kansei. Perception has its subjective part. For instance personal interests and competence, trends and fashions, interactive experience and temporal dependency are major factors capable of transforming an initial Kansei (Shütte, 2006). Social factors also take an important part in the early design process. From a human perspective the product acceptance depends on the context of evaluation, on the user psychological and physiological characteristics, on his socio-economic category, his age but also his desires, motivations, ideals and his social values. (Damasio, 1994) (Erner, 2009). These factors are a crucial parameter for the determination of Kansei (Caron G. , 2005).

The Virtual Kansei Design is used to rapidly evaluate the relationship between a person and a product and create a database describing and compiling these relations. Virtual product evaluation can also simulate the product in a given space. While evaluating a product itself, a designer is able to evaluate how it fits its targeted environment. For example a pen would not be designed the same way if it were meant to be used by a businessman working at its desk or by a student drawing in his bedroom. By immersing a person in a specific fitted environment while evaluating a future product, it is possible to give more information on the product itself and on the lifestyle, function and ambiance corresponding to the designed object. As Virtual Kansei Design has mostly been executed through computers, it is also visually centered. A few promising attempts have been made to substitute audio stimulus to visual stimulus (Mougenot, 2004).

Kansei Design describes the end-user to object emotional link. We study this approach in comparison with the Conjoint Trend Analysis which also expresses the link between social factors and design attributes to extract trends. The emotional impact a project has on the user is the centerpoint of both methods. Although virtual Kansei has approached virtual reality techniques, such as environment simulation and digital interactivity, the crafted tools of design are also widely restricted to visual content.

Kansei, just like emotion is not a directly observable object. Research has yet been led to evaluate

and measure Kansei and emotion. The next paragraphs reviews the major techniques used to quantify Kansei. Psychological, physiological and behavioral analyses are the three known types of emotions measurement.

- **Psychological (ψ)**

The self-measurement method is a common way of evaluating the human part of Kansei (Rouveray, 2006). This method consists in assessing one self's subjective state when in contact with a product. There are different ways of leading a self-measurement analysis, (Osgood C. , 1957), (Izard C. , 2007), (Mehrabian, 1997) (Padilla, 2001). In general during the self-measurement study, the subject is asked to grade his subjective state through scales composed of semantic terms. Terms can be classed in major categories (pleasure/arousal/dominance). They can also be opposed like in semantic differential scales (strong/weak; delicate/bold...) or can be standalone like found in semantic unipolar scales. These investigation methods have the advantage of transforming qualitative information into quantitative data and thus allow us to apply statistic calculatory methods onto subjectivity. Data processing time is rather long but the results are easily interpretable. Objections to these methods arose mainly because strict objective judgment cannot be obtained via arbitrary judgement (Lévy, 2007) (Nagasawa, 2002). (Desmet & Hekkert, 2007) pointed out that intercultural methods are impossible, due to the evaluation via semantic terms. This problem was overcome with the development of Iconographic Self-Measurement. Instead of semantic term, iconographic material is used to assess emotions. The Premo tool is based on facial expression (Desmet P. , 2007). Tested subjects are asked to identify themselves to characters expressing different feelings. As Ekman, (Keltner, Ekman, Gonzaga, & Beer, 2003) explains, facial expression has the advantage of being easily identifiable. The intercultural quality of facial expression reduces subjectivity in this kind of studies. However, the lack of ease in self-judgment can reduce fidelity between felt emotional states and expressed emotional states. The NPDIL develops methods based on the Geneva emotion bank (Scherer, 2005) and the Lang semantic scales (Bradley & Lang, 1994) which enable a more precise identification of the measured emotional state. In order to breach the methodological gaps of an exclusive psychological method we position towards the combination of psychological, physiological and behavioral data.

- **Physiological (φ)**

A completely different method to determine a subject's emotional state is to detect it by interpreting the physiological response to a stimulus. As will be explained later (cf. Figure 25) physiological and motor response helps interpreting the indirectly observable emotional state of a subject. In most

cases, physiological studies are not sufficient and act as complementary studies to refine global emotional assessment. However, data are directly collected in a quantitative state. They are also completely objective, due to the absence of control of the subject on measured parameters. This objectiveness makes the physiological emotional response independent of cultural affiliation. Here are the usual measured parameters:

System	Signals
Cardiovascular system	Electrocardiogram; blood pressure; blood flow and volume
Skin related	Skin electric potential; palm/forehead sweat level; electrodermal resistance
Muscular	Electro-muscular
Brain	Brain wave; IRM; CBF
Ocular	Pupils diameter
Circulatory	Blood flow and volume
Endocrinal	Hormonal concentration
Respiratory	Chest movement
Immune	Immune Rx; health state
Salivary system	Saliva Protein composition

Table 1 - Emotion physiological measurement (adapted from (Kim, Modeling cognitive and affective processes of designers in the early stages of design: mental categorization of information processing, 2011))

Many of these techniques have been used in Kansei based design process to identify reaction of a population to a product and modify the product parameter to optimize its emotional impact (Nagamachi M. , 2002). However, the risk in using physiological emotional state measurement seems to be the over interpretation of the collected data (Nagasawa, 2002) (Rouveyray, 2006).

- **Behavioral (β)**

Facial expression, postural and eye tracking, hand gestures examination contribute to the formalisation of the emotional states. For instance (Keltner, Ekman, Gonzaga, & Beer, 2003) developed a taxonomy linking facial muscular contraction with emotional state. As some expressions or postures are difficult to simulate, these analyses can enable the acquisition of precise interpretations (Bianchi-Berthouze, 2009).

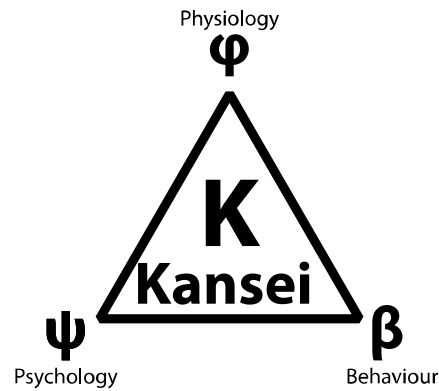


Figure 22 - Kansei dimensions

The preceding paragraphs depicted methods which are used to evaluate the impact of existing products or intermediate representations of these products. The evaluation results are used to specify products design attribute and thus raise the products overall quality. Each type of measurement methods give different data concerning the Kansei. The ideal protocol crosses self-measurement psychological, physiological and behavioural data (cf. Figure 22). In this research work this model is referred to as the multidimensional experience measurement model. The data processing time and complexity grows with each type added to the study. These methods enable the researcher to identify the emotional impact of a product or intermediate representation on a designer to end-user.

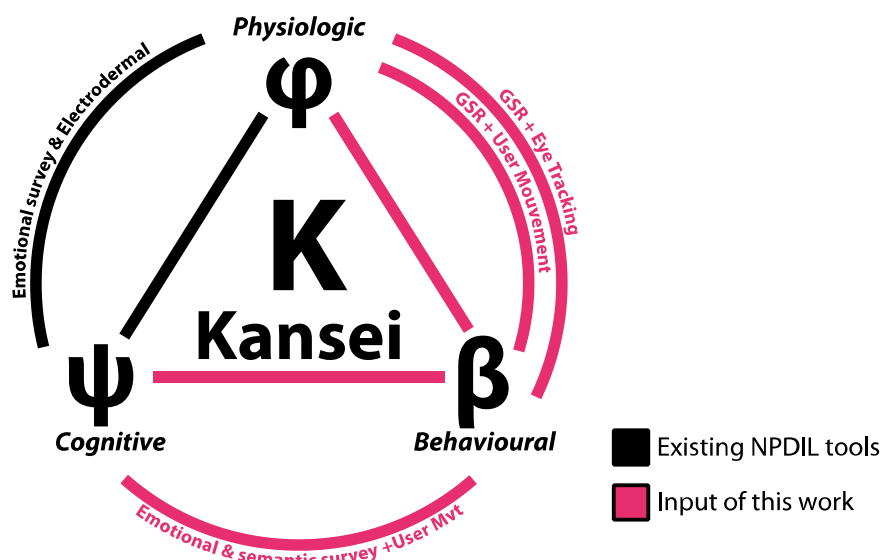


Figure 23 – Development of the user experience multidimensional measurement model

Based on prior studies operated in the NPDIL, we adapt the measures into a multidimensional measurement model grounded on the analyses and cross analyses of the different measured dimensions. (Mantelet, 2006)

Kansei Design is oriented onto understanding the relationship between a concept and a human being. The human being is a central subject of the methodologies presented in the prior section. These methods relate to advanced techniques in objective and subjective measurements. The next section presents the human related aspects of industrial design.

2.3 EMOTION AND HUMAN SCIENCES

Studying the relation between virtual reality and industrial design requires an understanding of the connections between the designer and his environment. The scientific statements necessary to the depiction of a perceptual, cognitive and emotional model of the designer are explored in the following section (cf. Figure 24).

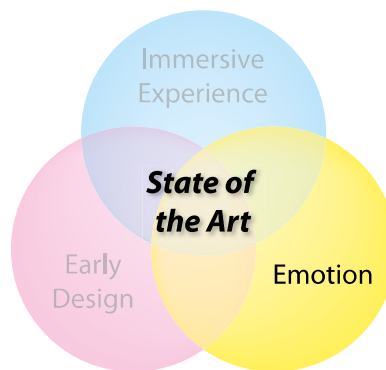


Figure 24 – Emotion component of the research work

For many years, emotion has been excluded from scientific research for a lack of direct observation possibilities. In the early 1950s the notion of emotion was intuitively described as the trigger of a bodily response. The psychologist W. James proposes a counter intuitive vision in which the emotional body reaction to a stimulus is prior to the emotion conscious awareness (Williams, 1890). Later, in 1970, the neurosurgeon Paul D. MacLean develops a definition of the human brain (MacLean, 1990). He claims that the brain is divided into three elements: reptilian, limbic and neocortical. From stimulus to behavioral response, the information may travel through two different paths: the upper path (neocortical, slow path) which is described since Freud (Freud, 1966) as the consciousness receptacle, and the lower path (limbic, quick path) where the emotion and personality center resides. Next emerges a cognitive view of emotion in which (Lazarus, 1991) explain that the neocortex intervenes before and after bodily response. In this way, (Mandler & Georges, 1992) refers to emotion as a signal from the sympathetic nervous system to alert the consciousness and enable a reevaluation of the environment. A more recent theory (Damasio, 1994) regards emotion and cognition as two

simultaneous interrelated processes which each take an important place in the decision process. For instance, the birth of an emotion is the superposition of the limbic representation of an object and the neocortical representation of the observer observing the object. Applied to industrial design, this analysis strongly correlates with Donald Norman's work (Norman D. , 1988): the limbic path being robustly linked with the visceral level and the neocortical with the reflective level.

From a synthesis of psychological, neurological, behavioral and physiological model found in this state of the art, we have erected a model of the designer. (cf. Figure 25). Our future argumentation development will mainly be based on this model. As the human-object relationship is difficult to apprehend with metrics, Pavlov analyzes responses of many natures to a given stimulus, and evaluate the relationship by combining these different measures (Pavlov I. P., 1903). This logic combination allows to bypass the complexity of control mechanism of human reaction. (Reuchlin M. , 1980)

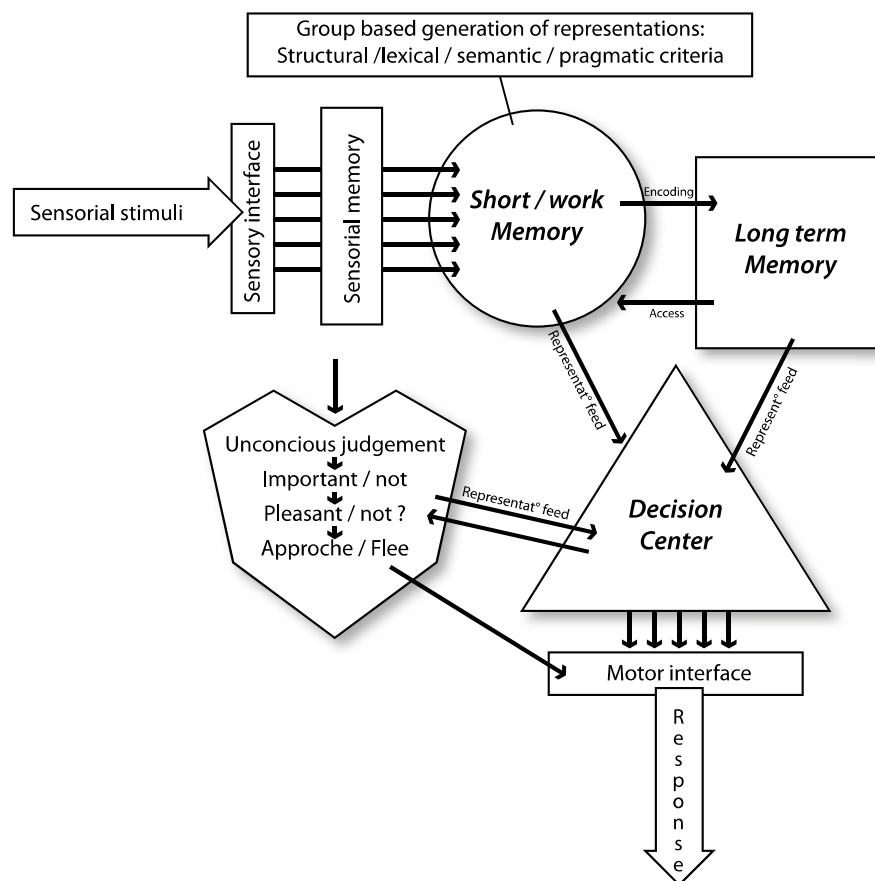


Figure 25 - Perceptual, cognitive and emotional model (Pavlov I. P., 1903) (Damasio, 1994) (Norman D. , 1988)

The depiction of the human being shown in Figure 25, is the latent basis for our research framework. This model is based on the stimulus-response procedure. An entering stimulus is received by the sensorial interface which transmits this stimulus to both the short term memory and the emotional center. The stimulus is co-processed by the cognitive and emotional centers. The stimulus results in a

response mediated by the motor interface of human.

A stimulus occurs when the environment changes from an initial state to another. The constant dual conscious and unconscious analysis of our environment constitutes the decision we take (Cuisinier & Pons, 2011). , decision about the possible operations and anticipated results (Uhlmann, 2007):

- Throughout the industrial design process, the designer assesses his work and his potential inspiration material (cf. Figure 17 p.34). This assessment is part of a cycle use by the designer to solve his design problem:
- Assessment of an input state with regard to correctness and appeal (bipolarity); this input usually is the output of the previous design action.
- Mental anticipation of a new state based on the previous evaluation and anticipation of operations that could invoke this new status.

To sum up, we summarize in this part the main definitions related to emotions from the discipline of psychology. The aesthetic judgment in design is composed both of an objective and a subjective process. Objective judgment relates to erected rules such as Gestalt theory or the chromatic circle of Isaac Newton. It is a calculated logical reasoning to determine if an object representation or its design attributes are acceptable, whereas subjective judgment is highly linked to the emotional and memory center of the brain and is not always conscious (Woelfel, Krzywinski, & Drechsel, 2010). As suggested before and in reference to Damasio's studies, both parts of the judgment (logical and emotional) are quasi-simultaneous and condition each another. This psychological view over industrial design gives us the theoretical basis to understand how information is processed during the different phases of design (cf. 2.2).

The precedent section shows a model synthesizing contemporary views on emotion and cognition. It also presents the involvement of emotions in the decision and design process. The following section presents a definition of virtual reality, immersion and spatialization as well as a review of the recent evolutions in the domain.

2.4 IMMERSION, SPATIALIZATION AND VIRTUAL REALITY

Another large orientation in industrial design is the computation of the design process towards the development of digital tools. Digital tools have been used in many fields to reduce development time,

cost or to ensure a low error, high quality process (Pasman, 2003) (Büsher, 2004) (Restrepo, 2004) (Kim, 2011). At the moment, immersive tools are not highly present in the early design process but rather more used in the detailed design phases. However, at the crossing between industrial design and innovative digital tools, we find virtual reality aided design (cf. Figure 26).

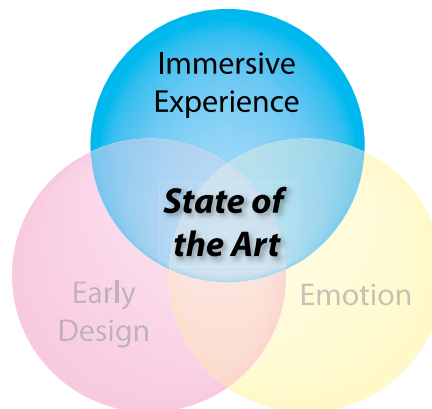


Figure 26 – Immersion realted component of the research work

Throughout this thesis the term *Virtual Reality* is to be understood in the way it is defined by Fuchs and al.: "*Virtual reality enables one or more persons to experience a sensor-motor and cognitive activity in a digitally created artificial world. This world can be imaginary, symbolic or a simulation of the real word.*" (Fuchs & Moreau, 2006). A certain virtual experience is qualified as immersive when a new motor and perceptual system is enabled to the user by a technical device. To be immersed into a certain space is to localize events and objects from a point of view belonging to this specific space. Spatiality is the three dimensional characteristic of an environment. Thus virtual reality techniques provide immersion of the user in spatialized environment. To discriminate the immersive from the spatial notion, here are two examples to illustrate this point. A painting may be immersive owing to its mesmerizing characteristics without being three dimensional. A three dimensional computer game might have three dimensional graphics however does not compel the user to integrate its environment, thus is not immersive.

It is now becoming common to encounter innovative products linked to virtual reality on daily basis. The Nintendo Wii, the 3D movie theatre experience via stereoscopic glasses, augmented reality on cellular phones... and many more applications of virtual reality emerge in every day's life. The standard modern user is ready to accept immersive interactions, and is often fond of them. In recent researches combining designers with mixed reality, participants showed enthusiastic comportment towards the use of virtual tools. (Lucero I. , 2000). This echoes in the virtual reality domain of Serious Gaming. Serious Gaming is a pedagogical tool using videogame strategies to teach or communicate a message (Nelson, 2011). As the society evolves, virtuality takes a bigger part in our everyday life.

Evolved man/machine interfaces such as affective computing or corporal engagement are more easily accepted. These are satisfying circumstances to propose a new vision of industrial design in which designer and future products interact through digital worlds.

The ever-growing digital calculation capacity is giving the digital tools a growing realistic rendering power. In the last years hybrid rendering technologies enable the user to experience 3D models in real time as well as a high graphical quality, hence giving a high sense of presence (Barfield & Danas, 1996). From Nintendo Wii™ to Lumiscaphe Patchworck 3D™, the graphical and calculating power difference is huge and so is the difference between the levels of visual detail. Real time rendering supposes that all 3D objects in the 3D scene are recalculated throughout time and interaction with the 3D users view point and actions (Dinh, 1999). This technique usually enables great interaction power but poor graphical quality and level of detail. Pre-calculated 3D means that the virtual scene has been calculated before use. It is time consuming to generate and enables a near low to inexistent interaction with the 3D world, due to recalculating time and a lack of possibilities to modify the virtual environment parameters. Hybrid 3D mixes pre-calculation and real-time rendering, therefore it gets a mid/high graphical and detail level with a mid/high interaction power and possibilities. The lag effect is the latency between VR user's actions and their virtual feedback. It can engender an incoherent feeling or worst: simulation sickness. The lag is the embodiment of the compromise between rendering calculation time and interaction realism.

The arrival of such technologies has an impact on industrial design. Real-time quality has not been high enough for the designer to evaluate their work with precision. Considering the calculation time of high quality models (textures and polygon number) the interaction level between product and the industrial designer is near to null. Digitalization of design process requires both the properties of Hybrid rendering: visual quality and real-time interaction. Furthermore, the designer seems ready to accept immersion in its daily design activity.

2.5 SYNTHESIS OF THE STATE OF THE ART (STATEMENTS)

The purpose of this state of the art is to present an innovative research area, given the thematic concerning *early design*, *emotions* and *immersive experience*.

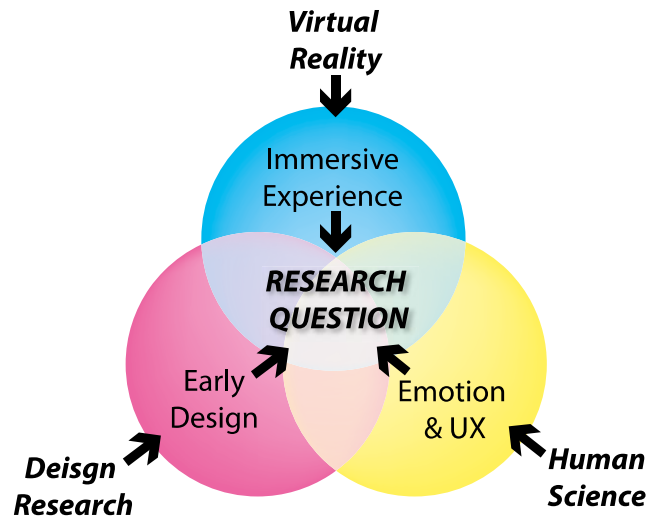


Figure 27 - Identification of an innovative research question

This synthesis is divided into three sections (cf. Figure 27). The first section presents the underlining models necessary to the scientific manipulation of concepts related to *early design*, *emotions* and *immersive experience* (§2.5.1). The second section recounts the limitations of early design (§2.5.2). The third section presents the statements identified through our readings with respect to the domains of *early design*, *emotions* and *immersive experience* (§2.5.3). These statements are the basis for further development of the research question presented in Chapter III.

2.5.1 CORE MODELS SUPPORTING THE RESEARCH FRAMEWORK

Our state of the arts leads to two evident models that support our research along this study (cf. Figure 28).

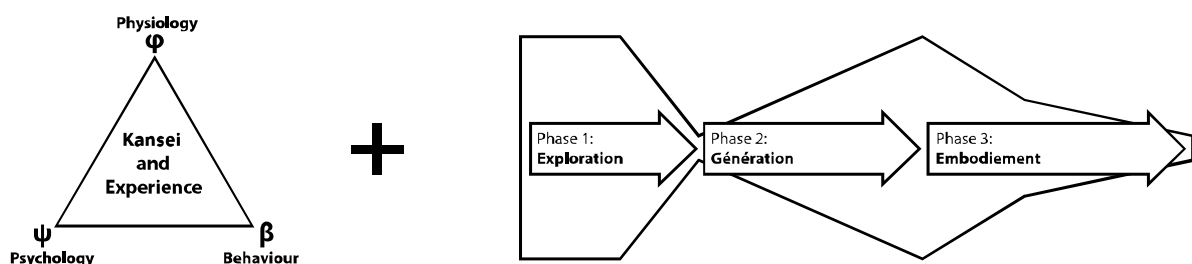


Figure 28 – Core models of the study

The first model is extracted from the domain of human sciences. It represents the human experience and Kansei of a related entity (§ 2.2.5.1). It is based on a cross point of view between the physiological, psychological and behavioral approaches.

The second model summarized from the domain of design research presents *Exploration, Generation and Embodiment* as the three phases of the design process (§2.2.3).

These two models are central to our study. They are the bases for our research question and hypothesis, and above all constitute the support for the design of the experimentations as well as the basis of our modeled contribution.

The following section provides information on the limitations of early design representations with regard to the opportunities offered by the available representations such as spatial immersive display.

2.5.2 LIMITATION IN TRADITIONAL EARLY DESIGN REPRESENTATIONS

Intermediate representations depict the product as the design process is executed. Intermediate representations are used for product evaluation in order to identify any defects, find alternative solutions, estimate fabrication time/costs and stimulate designer/designer or designer/client dialogue (Göbel, 1994). They are here to simulate essential product properties and are used from the first ideas concerning the future product to the final artifact rendering. During the design process, hypotheses are made and evaluated by means of these intermediate representations. Often these representations are hypercentered on visual evaluation. As the fuzzy front end of design goes, hypotheses made in this phase concern many of the sensorial modalities (Bassereau J.-F. , 2001) (Guenand, Gapenne , Lenay, Maillet, Stewart, & Thouvenin, 2007-08). It is difficult for a designer to evaluate future products properties when he is unable to appreciate them under their multimodal form (Kadri, 2007). A design defect can even only be detected once the final prototype is rendered and subsequently release additional funds or mobilize a design team for an undetermined time. Thus it is crucial to identify any possible defect or promising designs through intermediate representations as soon as possible to ensure a successful and competitive product. A short and inexpensive design process is majorly possible because of efficient intermediate representation. Traditionally and in an orderly fashion, the different intermediate representations are: *moodboard, drawings, physical mockups* and *digital mockups*.

The design process is dotted with intermediate representations to help decision making and evaluation. However, these representations have limitations and embody only part of the design issues. The more the representation simulates the final product, the better the represented solution can be evaluated, the better the strategic decisions concerning the object design can be trusted (Kadri, 2007). The designing team may rapidly experience the future product through 2D techniques

such as moodboards or drawings (Stones, 2007). The 2D medium gives the designer the possibility to think over the necessary gaps of his fuzzy representation. On the other hand, 2D representations give no dynamic or interactive possibilities and provide only the option to explore the object or universe through a single point of view per representation. Another limitation of the 2D representation is the lack of sensorial modality allowed by this type of representation. The 2D means does not allow complex sensorial interaction. For example, the moodboard collage only simulates an atmosphere using the visual sensorial modality (Bassereau J.-F. , 2009). New numeric representations enable a certain liberty on parameter modulations. For instance a color parameter can easily be changed on a digital support. In general visual evaluation mode has a wide monopoly over the early intermediate representations. Few are the haptic, olfactory, auditory... rapid representations made available to the designing team in order to evaluate what can emanate from the future product.

To summarize, an intermediate representation is a formal hypothesis generation and evaluation tool. It enables the identification of defects and assets as well as the dialogue over these design attributes. In the contemporary design process, the intermediate representations are highly visual. The more the design process advances the more precise design attributes are represented. However, the state of the art has pointed out that the traditional representations have the limitations described in the precedent paragraph. The next section presents how virtual reality can optimize these representations, given the design and human context.

2.5.3 STATEMENTS ON COMMON AREA BETWEEN VIRTUAL REALITY, DESIGN RESEARCH AND HUMAN SCIENCE

This part is composed of a synthesis and classification of the major elements identified through our readings:

Figure 29 sums up the major assessments exposed in this thesis. They are divided in four categories, centered on the evaluation of early industrial design hypotheses (cf. Figure 29).

First of all, sensorial design researchers have criticized the lack of sensorial evaluation during the design process. Most of the assessed parameters in the beginning of the project are visual. Today, there are few tools capable of presenting, categorizing and evaluating strategic early multimodal pieces of information concerning the future product.

Secondly, in comparison to digital support, the 2D analogue supports are static, non-interactive and

non-modifiable. With the exclusion of perceptual substitutive mechanisms, the only sensorial modality concerned during the use of a 2D medium is visual. However, the traditional way of early designing is centered on the simultaneous creation and evaluation of rapid intermediate representations.

We also know that it is possible to measure the emotional impact of a product on a person and that this impact is partially triggered by sensorial modalities.

Finally the exposure to the atmosphere and style adjacent to the brief helps to construct a solid design issue. When evaluating a product, the environment modifies the perception of the product. Thus a calibrated virtual environment can contextualize the product assessment.

- As previously stated, the more a representation embodies a design problem the more the problem can be handled. In paradox, these representations need to be ambiguous so that they leave space for design thinking. As these representations are supports for inspiration, they are required to be unfinished and with a certain degree of abstraction (Buxton, 2007). To sum up, a good design intermediate representation has a good balance between the information it conveys and the questions it asks according to its time framing in the design process. Concept and knowledge theory identifies these spaces as "*conceptual space*" (questions, expands) and "*knowledge space*" (answers, sums up) (Hatchuel & Weil, 2009). Representations found in the early design process are more of a conceptual nature in opposition to late design representations which are proposals.
- Vividness is the power with which an object imposes itself to consciousness via emotional images. A vivid message gets more attention because of the intense emotions it evokes (Kelley, 1989). (Norman D. , 1988). A vivid media would exhibits the appearance of life.

To summarize, intermediate representations are a formal hypothesis generation and evaluation tool. They enable the identification of defects and assets as well as open the dialogue over design attributes. In the contemporary design process, the intermediate representations are highly visual. Time wise, the more the design process advances the more precise design attributes are represented. During early design, working on the product related Kansei implies a medium that enables a good apprehension of the emotional aspect of a trend and enables the represented trend to appear vivid or as being part of the designer's world.

The data gathered has shown that virtual reality is scarcely used in early design but rather more in the detailed design phase. It is often applied, not for inspiration, nor for quick externalisation, nor for

conceptual exploration but instead more as a final milestone to assess final design hypothesis.

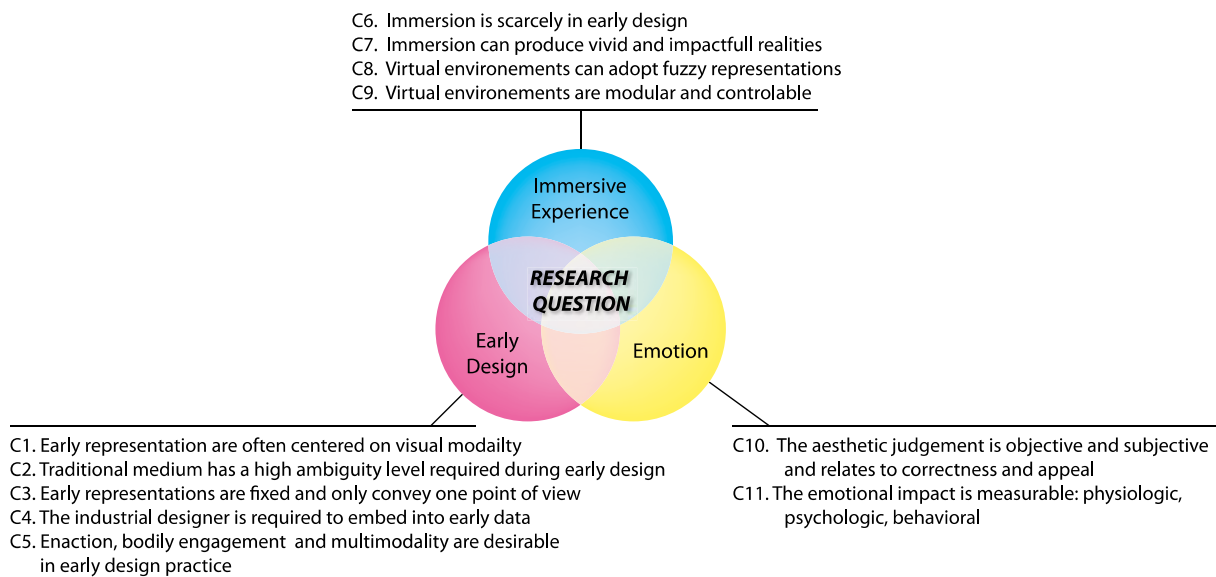


Figure 29 – Key statements

Our statements shows an opportunity for progress and theoretical junction between industrial design, virtual reality and designer experience. Our scientific positioning and originality added to the statements on the avallable litterature leads us to the construction of research question.

3 CHAPTER III - RESEARCH QUESTION AND HYPOTHESIS

3.1 INTRODUCTION

In chapter III we state our research question and develop the hypotheses of this thesis. They are theoretically based on statements concluded from the state of the art of early industrial design, psychology and physiology of emotions and design dedicated to virtual reality.

The research question in this thesis concerns **how the early industrial design process can be augmented by a spatial immersive workspace**. In the state of the art, early design is described as a sequential process including the inspirational phase (phase 1) which is the gathering and processing of contextual data based on the design brief, and of the generational phase (phase 2) which is characterized by the exploration of formal solutions to the brief.

In order to answer to this question we formalize two major hypotheses:

- **Hypothesis 1** supposes that the emotion induced by a design trend is modified by the spatial immersive experience of the moodboard. (§3.3.1)
- **Hypothesis 2** suggests that transposing the traditional early design tools into a spatial immersive workflow modifies the emotional early design activity and the related design concepts.(§3.3.2)

3.2 RESEARCH QUESTION

Taking in account the statements made in Chapter II we propose to study **“how the early design process can be augmented by immersion in a spatial industrial design workspace.”**

This thesis aims at the optimization of the design process. Besides studying how the industrial designer's activity can be optimized by a spatial immersive workspace, we study the impact of spatial immersive tools on the concept produced by the industrial designer and on end-users feel about this product.

By relating to the industrial designer's needs and to the social and technological opportunities offered by the recent growth of immersive technologies, we have chosen to investigate what an innovative spatial immersive workflow could provide to the early industrial workflow. This research question implies the development of an experimental case study based on prototype of the immersive tools. The specifications for this prototype are developed on the bases of the analysis of the industrial designer's needs, their traditional tools and our expertise in design science and virtual reality techniques.

Our observation has shown that virtual reality is scarcely operated during early design but rather more during the detailed design process. Thus a knowledge gap appears at the junction of the early design research and the application of immersive technologies. Our research intends to fill this gap by understanding how the immersive technologies can enrich the industrial designer's activity and its outputs. In addition, this research work intends to understand how virtual reality can be of major interest to the overall early design activity as a process.

Our research is essentially focused on the early industrial designer's experience of his workspace and how innovative tools can modify his workflow. Furthermore it aims at clarifying the impact of a particular immersive experience on the industrial designer's activity and production.

By overlapping the industrial designer's reality with the virtual reality provided by the tools and data he operates with, we intend to help the designer to emotionally and cognitively commit to a project, express his ideas and assess his propositions. The immersive workflow aims to deeply engage and confront the industrial designer to the design problems and to the solution he externalizes.

In addition, by focusing on a sequential early design process, we intend to observe and characterize the relationship between two steps of the early industrial design process: the inspiration phase and the generation phase. Thus we can develop further specifications for immersive tools dedicated to

the early design activities. In order to meet the industrial needs and to enable laboratory experimentations, we provide a functional tool prototype, its evaluation as well as specifications for future versions.

We thus characterize optimization both by the beneficial modification of the designer's experience of design and also by the beneficial modification of the design concepts acceptance by future end-user. This work brings a significant contribution to the *digitalization and optimization of the design process*.

3.3 HYPOTHESES

In order to answer to our research question about "how the early design process can be augmented by immersion in a spatial industrial design workspace?" we propose the following hypotheses:

HYP 1: *The Kansei induced by a design trend is modified by a spatial immersive experience of the moodboard.* (cf. Figure 30)

HYP 2: *The emotional activity during early design and the concepts which are the product of this activity are modified by a transposition of the traditional early design workflow into a spatial immersive workflow.* (cf. Figure 30)

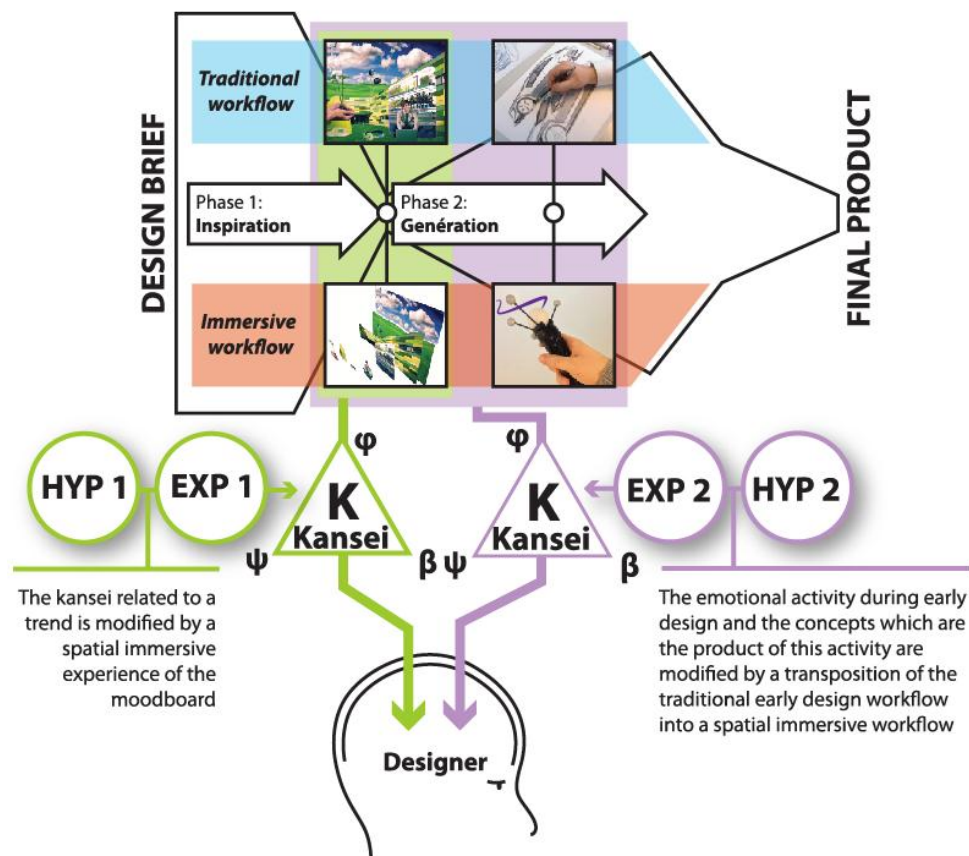


Figure 30 - Hypotheses and Sub-hypotheses

The first hypothesis involves the inspirational phase of the early design process, however the second hypothesis integrates both the inspirational and the generational phases.

3.3.1 HYPOTHESIS 1: THE KANSEI RELATED TO A DESIGN TREND IS MODIFIED BY THE SPATIAL IMMERSIVE EXPERIENCE OF THE MOODBOARD.

Hypothesis 1: The Kansei related to a trend is modified by a spatial immersive experience of the moodboard (cf. Figure 31). In order to understand how industrial design can be optimized through immersion, we first observe how the Kansei related to a studied set of design trends is impacted by the support of a moodboard (EXP1). The different tested supports are the traditional two dimension moodboard and the spatial immersive moodboard type (cf. Figure 32). Our aim is to identify the objective effect of a transformed Kansei related to the use of the new immersive moodboard and clarify if this change can be a benefit to the early design process. This effect will be used as a basis to model the relation between the designer and the immersive moodboard and to specify spatial immersive tools for early industrial design.

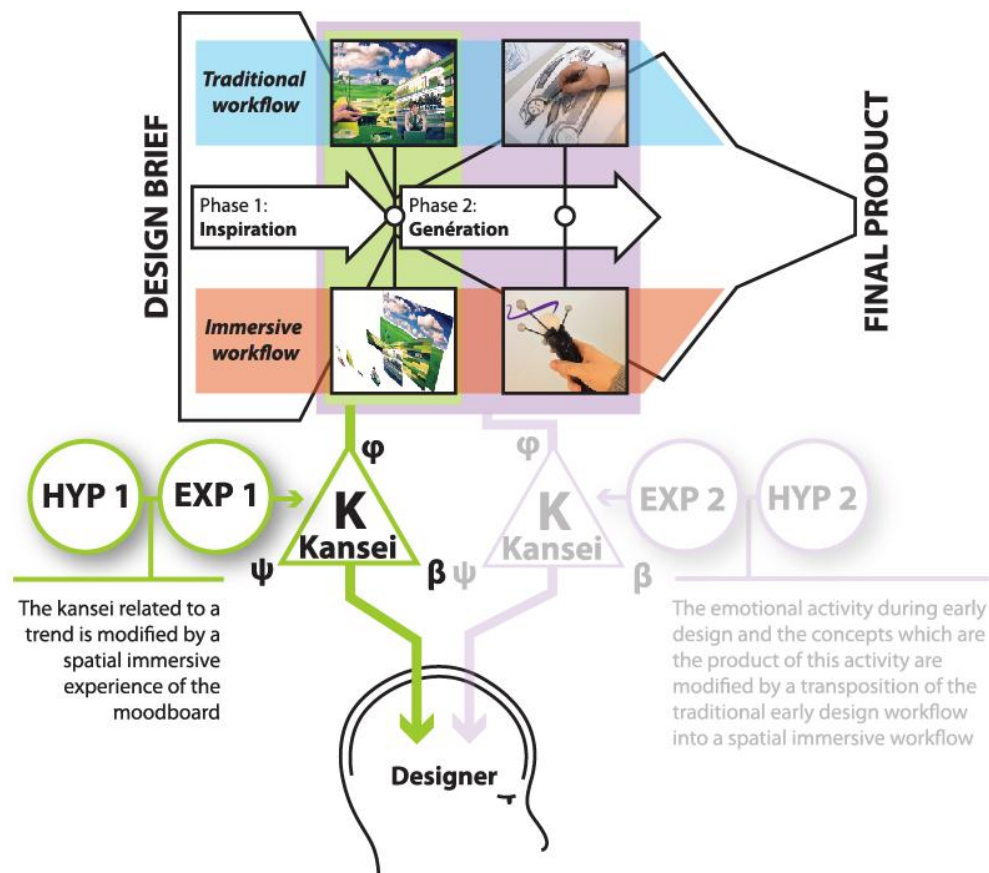


Figure 31 - The Kansei related to a trend is modified by a spatial immersive experience of the moodboard.

The importance of developing knowledge on the product to be designed and the necessity for the industrial designer to be deeply engaged in the early analysis, both justify why we have chosen the moodboard as the targeted tool. The moodboards present a high interest for our study, for they are one of the very first representations of the future product. They also constitute a visual access to a

trend associated to this product, in the broadest sense of the term (lifestyle, ambiance, feel, value...). The progressive elaboration of new design tools will enable us to study the impact on the designer's experience and perception. Thus we intend to optimize how the designer projects himself into early industrial design data on the very first formalized representations.



Figure 32 - Example of a moodboard transcription

In order to eliminate bias, the moodboards used as stimuli for our study are constructed, selected and spatialized with great care (§4.2.3.5). The immersive and traditional moodboards format must be rigorously similar, except for their spatial difference (cf. Figure 32).

In order to develop this hypothesis, we have established an advanced model of the Kansei (cf. Figure 33). Our focus bears on the industrial designer's experience from semantics to emotions through body engagement. Given the intrinsic complexity of the observed object, our psychological, physiological and behavioral multidimensional approach of the Kansei contributes to the originality of this hypothesis and thoroughness of the expected results.

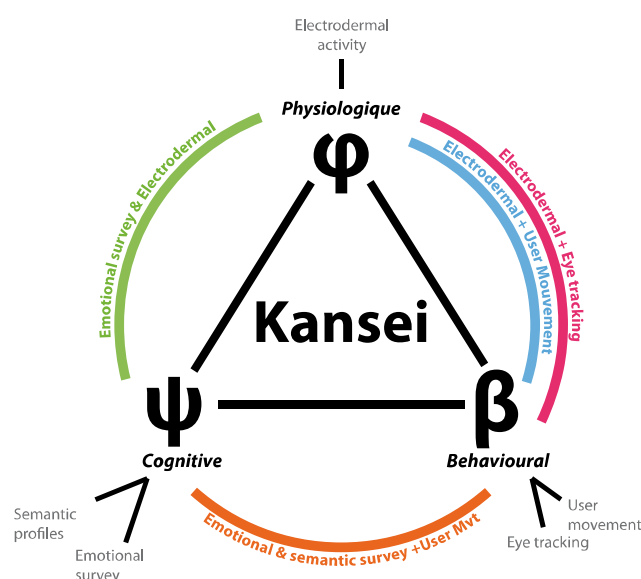


Figure 33 – Kansei/Experience single and combinatory measures

Furthermore and with regard to the expected results, the extent to which immersive spatialization is tested can be enlarged to generational tools and thus enable to study the early process ranging from brief to inspiration and generation, unto the evaluation of design concepts (EXP2).

3.3.2 HYPOTHESIS 2: EMOTIONAL ACTIVITY DURING EARLY DESIGN AND THE CONCEPTS WHICH ARE THE PRODUCT OF THIS ACTIVITY ARE MODIFIED BY A TRANSPOSITION OF THE TRADITIONAL EARLY DESIGN WORKFLOW INTO A SPATIAL IMMERSIVE WORKFLOW.

Hypothesis 2: The emotional activity during early design and the concepts which are the product of this activity are modified by a transposition of the traditional early design workflow into a spatial immersive workflow (cf. Figure 34). We expect the study of the first hypothesis to show that transposing the moodboard onto a spatial immersive support will bring benefits to the designer in his relationship with early design data (cf.4.2.4). Beyond observing only inspirational material, this second hypothesis aims to study how immersive spatialization impacts the early industrial design process in a much broader manner by also including the concept generation phase. This second hypothesis is centered on the whole workflow rather than on a simple step with a single tool. We thus study a sequence composed of three fundamental steps: enunciation of the design problem (brief), inspiration phase and generation phase. This enables the observation of the link between the activity of inspiration and that of generation.

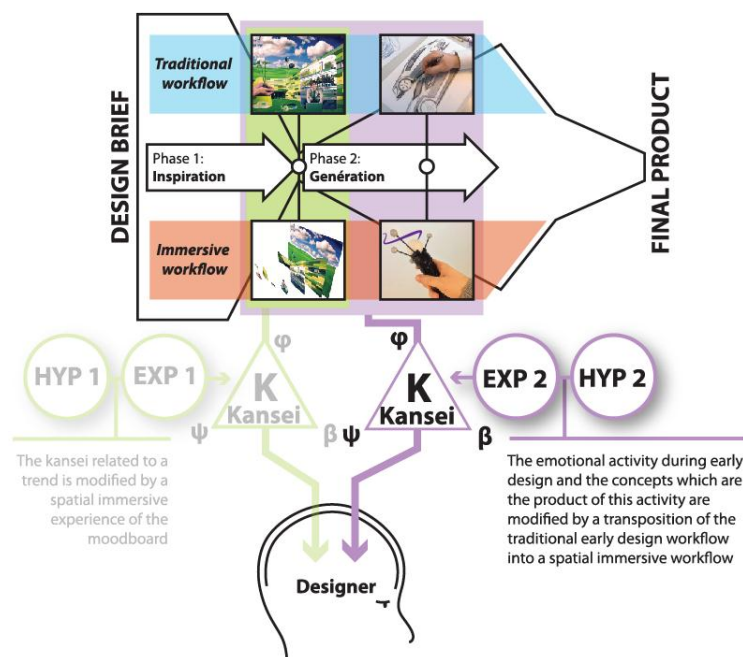


Figure 34 – Hypothesis 2: The emotional activity during early design and the concepts which are the product of this activity are modified by a transposition of the traditional early design workflow into a spatial immersive workflow.

Supposing that the transformation of a traditional moodboard into immersive moodboards increases the emotional physiological and psychological activity (cf. EXP1), we chose in EXP2, to focus on the industrial designer's emotional activity during the early industrial design process. By monitoring the emotional activity during the inspiration and generation phases, we expect to observe an effect of the modified emotional activity on the extent to which the experts and potential users experience design concepts. We also expect to identify how immersive spatialization tends to modify the industrial designer's emotional activity in its time framing and its intensity. Finally we expect to understand if the immersive early design workflow and the related intermediate representations provide a better vector for semantic and emotional link between the designer and the end-user.

In order to reduce the complexity of the study and to enable the detection of causal effects of spatial immersion, we have voluntarily simplified the early industrial design process to an essential workflow. In order to recreate and compare a traditional and an immersive design workflow, we organize them into a brief, including the typology of object to be designed, a notorious brand for which the designers are hypothetically working, as well as a moodboard capturing the essentials of the future products context.

3.3.3 KEY POINTS OF THE RESEARCH QUESTION AND HYPOTHESIS

This thesis aims to explore in what way the design process optimization can benefit from the finding of complementary attributes between industrial design and virtual reality. In order to achieve this goal, it is important to understand the needs of industrial designer as well as the opportunities delivered by the immersive technologies.

Thus we address a research question concerning ***“how the early design process can be augmented by immersion in a spatial industrial design workspace?”***. To answer to this research question we develop two main hypotheses: HYP1 confronts an immersive design tool to a traditional design tool. Hyp2 focuses on the comparison of a whole industrial design immersive workflow to a traditional one.

4 CHAPTER IV - EXPERIMENTAL STUDY

4.1 INTRODUCTION

Chapter IV presents in detail the experimentations related to the two hypotheses (cf. Figure 35).

Experiment 1 (EXP 1) is related to upon HYP 1. EXP 1 aims to detect the effect of a spatial immersive workspace during the inspirational phase (§4.2). We have led a study based on a comparative protocol confronting 16 industrial designers to immersive and traditional moodboards. This study is theoretically based on our multidimensional model (cf. Figure 33).

Experiment 2 (EXP 2) is associated to HYP 2. The EXP 2 is planned to compare an immersive industrial design workflow to a traditional design workflow (§4.3). In this experiment we add the concept generation phase to the inspirational phase to observe a complete workflow. More specifically this experimentation is set to identify the differences and the benefits linked to an immersive workspace during the inspiration and the generation phases of the early design.

The sub-sections of this chapter contain the procedure, the results and discussion of the experimentations. Lastly, this chapter assesses the validation of the hypothesis.

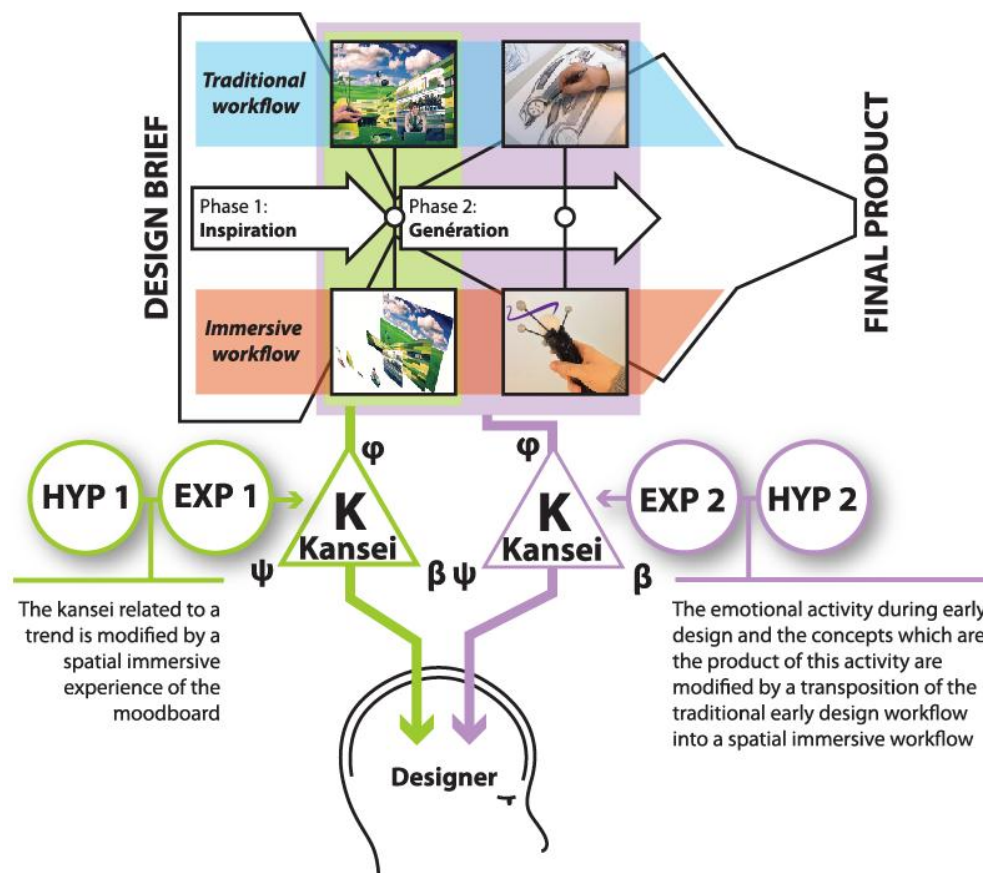


Figure 35 - Structure of experimental study

4.2 EXP 1: COMPARATIVE STUDY OF IMMERSIVE AND TRADITIONAL MOODBOARDS EXPERIENCE

This first experimentation is an empirical study aimed to answer HYP1: *The kansei related to a trend is modified by a spatial immersive experience of the moodboard*. EXP1 will be presented along this plan:

- Context → § 4.2.1
- Objectives → § 4.2.2
- Method → § 4.2.3
- Results → § 4.2.4
- Discussion → § 4.2.5
- Conclusion → § 4.2.6

4.2.1 CONTEXT

As it has been pointed out earlier in the state of the art, the designer needs to investigate and define the kansei dimension for the future products as soon as possible. Moodboards are the first synthetic representations of the product and are traditionally the first kansei support for assessment. They assist the designer in the validation of specific design attributes and of an overall style and direction for the project.

This first experimentation requires the design of innovative appropriate early representations (immersive moodboards) providing support for early kansei identification. This representation must convey a high positive emotional impact on the designer and inform him of the interesting trends and of the high-level and low-level design attributes (Mougenot, Bouchard, Aoussat, & Westerman, 2008). It must also provide a good abstraction level to give way to a fertile concept generation phase.

As far as representing an ambiance, a lifestyle or a trend, it is likely that the static two dimensional representations should not be the most impactful media available. We propose to expand the trend data in a spatial immersive environment (cf. Figure 36). By adding depth to moodboards and keeping to the initial moodboards composition, a three dimensional trend environment is created. The immersive moodboard keeps on presenting a scene, as does the traditional moodboard, but the three dimensional representation adds new possibilities as it allows interaction between the designer and the trend. This results in confronting the designer to a reality produced by the immersive or traditional moodboards.



Figure 36 - Example of a moodboard transcription

The immersive space is collocated with the real space and a motion parallax renders the experience of this 3D trend environment logical, as the perspective is recalculated in real time. The 3D trends are retro projected on the stereoscopic screen which acts as a window from the real environment to the virtual trend environment. What was originally a static picture becomes a set of 3D billboards participating in the illusion of a vivid and plausible world. While the perspective is modified according to the designer's eye position and the rules of a realistic environment, the individual perspectives of each billboard picture are different. Using two dimensional images as raw material for the construction of these virtual environments contributes in keeping this representation a fast and simple tool. The depth axis augments the space available for trend information. It also enables the designer to see behind an object by adjusting his point of view and thus to bypass occlusion. In this way the designer is also able to combine different objects in its immediate eyesight by simply walking from a point to another in the real world.

4.2.2 OBJECTIVES

The aim of EXP 1 is to detect the effect of the spatial immersion of a moodboard on the kansei related to a design trend.

The objective of this experimentation is to compare the kansei related to an immersive moodboard to the kansei induced by a traditional moodboard. To achieve this goal we compare the two types of moodboard in order to:

- Quantify and compare the impact of the immersive and traditional moodboards on the designer's emotions and experience.
- Determine and compare the semantic and emotional profiles related to the moodboards

according to the evaluation in both cases.

- Explore and compare the users' behavior regarding the different stimulus.

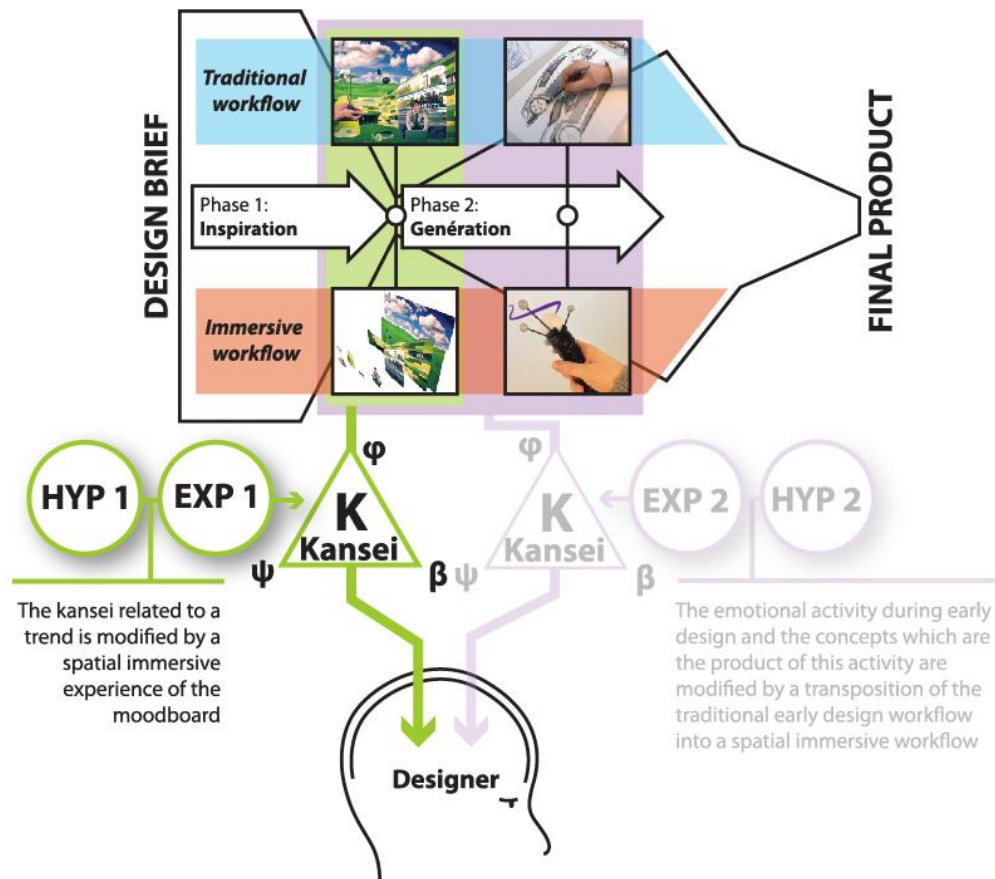


Figure 37 - Structure of EXP 1

4.2.3 METHOD

To understand how the early activity of industrial design can be modified with immersive techniques, we first decide to observe the relationship between the designer and the trend support. We study the difference between the kansei induced by an immersive and by a traditional moodboard both built with the same elements. We construct a two-condition based comparative study in which a panel of 20 designers is shown 2 immersive moodboards and 2 traditional moodboards in a randomly balanced method. They are asked to fill a series of questionnaire concerning their experience. The traditional and immersive moodboards are both shown on the same screen and in the same format (height 180mm x length 240mm) to subtract any bias due to the display size. Our method is to isolate a participant in controlled spatial *immersive condition* and compare his experience of an immersive moodboard with that of a traditional moodboard.

4.2.3.1 KANSEI MEASUREMENT

As affect, feelings and emotions are so volatile and not directly observable objects, we develop a method to objectively measure the designer's experience. We observe responses to controlled stimulus throughout our experimentations. To understand kansei, we base our studies on the analysis of physiological, cognitive and behavioral components. By measuring these various parameters and crossing the data, it is easier to reach a robust conclusion concerning the phenomenon observed between stimulation and response. For instance the understanding of a phenomenon is reinforced when two of the measures echo themselves with a strong correlation. This helps bypassing the inbuilt human reaction control mechanism. By combining these different data sets, new meaning can be unveiled.

- **Physiological component**

To model the emotional physiological arousal response, we have chosen to use electrodermal test also known as Galvanic Skin Responses. This device is the most appropriate measurement owing to its advantages, including high sensibility, reliability, time framing, simplicity of use and its low price. It provides continuous information and detects very sensitive amount of arousal.

- **Cognitive component**

The cognitive response to the stimulation is measured via a semantic differential questionnaire . The combined questionnaire created to assess the cognitive component is first composed of a set of 10 semantic descriptors and their established antonyms per moodboard. The list of semantic descriptors is obtained beforehand by the way of pilot studies through designers' verbalization, selection and sorting. These are used to understand the semantics restored by a moodboard to a designer during the experiment. The questionnaire also includes a set of 10 emotional terms per moodboard, obtained via precedent pilot tests through a selection of terms in an extensive list (Kim, Modeling cognitive and affective processes of designers in the early stages of design: mental categorization of information processing, 2011) (Scherer, 2005). Via this questionnaire, designers are also asked to evaluate the valence and intensity of their emotional state when stimulated by trend representation. As it is likely the immersive and traditional moodboards only induce secondary emotions during cognitive emotional evaluation, we have left out the study of dominance rather used to assess primary emotions.

- **Behavioral component**

Behaviors are registered through two major measures: The eye tracking is the first monitored

measure. When facing a stimulus, the designer is equipped with an eye tracking helmet indicating where his gaze position is. Eye tracking reveals the visual exploration behavior. This information is necessary in order to discriminate the elements composing the stimulus.

The second measure is the variation of point of view and head position in space. As three dimensional perceptions are not only due to stereoscopic view but also to movement in space, the movement is also an indicator of the participant's engagement and his desire to experience the immersive environment. This measurement is not intrusive, for it is monitored with infrared optical cameras.

The exhaustive list of combinations made to understand kansei are the following (cf. Figure 38): The combination between emotional questionnaires (ψ) and galvanic skin response (ϕ) may confirm the felt emotions of the designer panel. Pairing emotional questionnaire and users' movement can be used to determine specific behaviors due to spatialization of the data. An indicator of the potential capacity of an object contained in the moodboard to arouse the designer emotion can be created by combining galvanic skin response (ϕ) to gaze position data (β). And at last the galvanic skin response (ϕ) can be combined with the designers' point of view position (β) to detect and correlation between movement and galvanic skin response.

In order to compare the impact of the immersive to a traditional condition on the moodboards experience, precise information is necessary to interpret and conclude on the collected data. The correlations between the different measurements participate in the creation of refined data. We expect the finesse of these results to help us with the interpretation of the designer's emotional state and the detailed characterization of his experience.

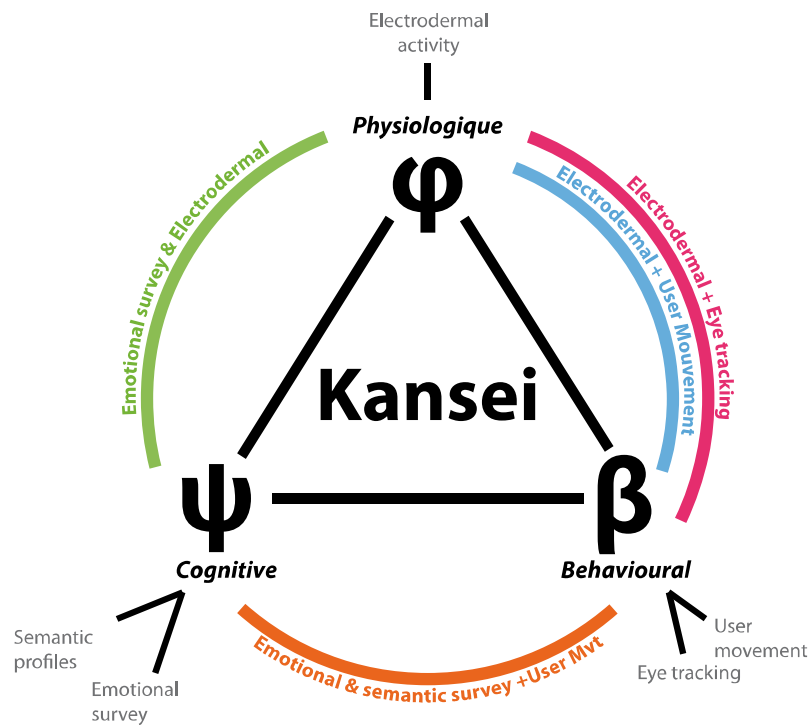


Figure 38 - Observed physiological, psychological & behavioral data cluster

4.2.3.2 PARTICIPANTS

As a part of the pilot studies, 18 master's degree students of Arts et Métiers ParisTech take part in the experiment. They have a minimum of 3 years of academic industrial design training. They are different from the designers involved in the pilot tests.

In addition, 16 professional designers take part in the formal experiment (cf. Figure 39), 10 of which are novice designers with an average of 3.3 years of experience and 6 expert designers with an average of 6.5 years of experience (87% men, 13% women). The 16 professional designers have a different understanding of the immersive experiences: 18% have already worked with immersive design environments, 43% have already been submitted to immersive environments and 39% are virtual reality neophytes.

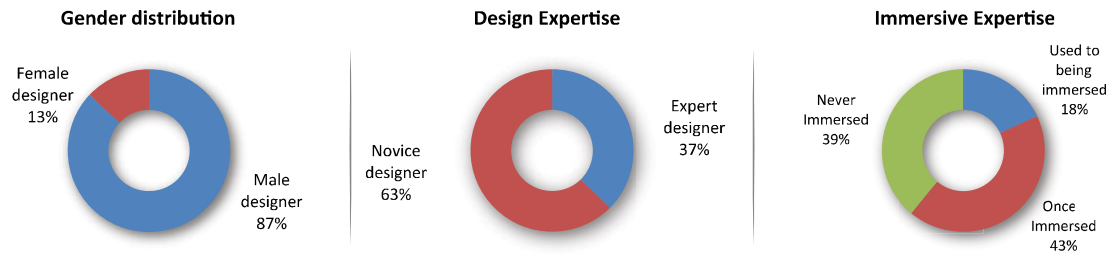


Figure 39 – EXP1 Population categorization

4.2.3.3 EQUIPMENT

The experiment takes place on the virtual reality platform of the NPDIL. This space is confined and user stimulation and data monitoring is fully mastered so that no bias can disturb the ongoing experiment. The following figures explain the setup of the experimentation (cf. Figure 40).

For the immersive application we use a Wall type stereoscopic display with a large-sized screen (2.4 meters by 1.8 meters) centered at 1.3m from the ground. The screen resolution is 1024 by 768 pixels. The subject is facing the screen at a distance of approximately 1.2 m. Under these conditions, the screen fills a large part of the visual field (about 90° in the horizontal field and 20° up and 50° down on a vertical field of view). The remaining equipment is listed in the following paragraph.



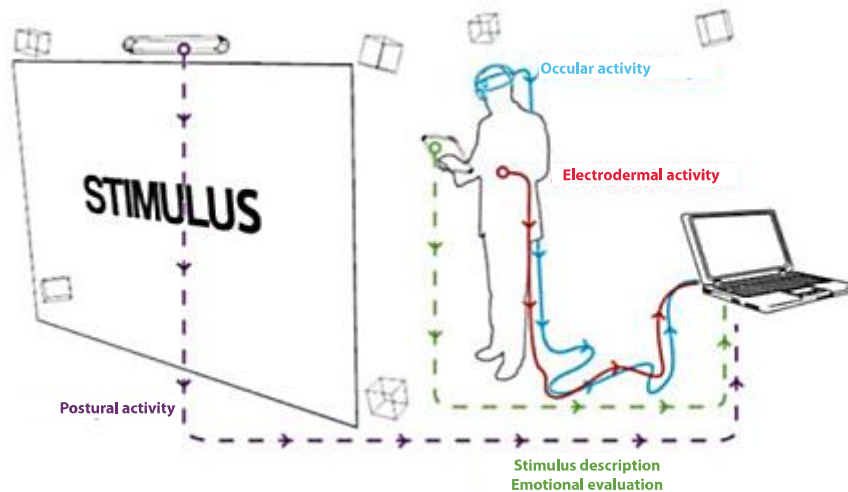


Figure 40 - EXP1 Kansei measurement platform

- 6 infra-red video cameras and a depth camera monitor the participant's movements.
- A mono-ocular head mounted eye tracking system records the participant's gaze position.
- The electrodermal system records the galvanic skin response of the participant.
- For stereoscopic vision the user is equipped with circular polarized goggles.
- The participant is provided a mobile touch tablet in order to complete the questionnaire.
- An assortment of 4 moodboards is provided as stimulation material via stereoscopic display.

4.2.3.4 PROCEDURE

The protocol engages the participant to be exposed four times to a different stimulus moodboard. The stimulation is controlled so that every participant is submitted to 2 immersive and 2 traditional moodboards with a random balanced method. Traditional and immersive moodboard of the same trend cannot be seen by the same participant. After each stimulation, the designer completes a task composed of two phases.

Phase 1: The tested designer is asked to describe the current stimulus moodboard using the available semantic differential scales questionnaire proposed on the touch tablet.

Phase 2: The designer taking part in this experiment is asked to describe the emotions induced by the current stimulus moodboard using the available emotional one bound scales questionnaire proposed on the touch tablet.

While the designer is stimulated by alternating 20 seconds of immersive and traditional moodboards,

his ocular activity is measured with the mono-ocular HED. Each designer is equipped with the eye tracking system, be it in *immersive condition* or in *non-immersive condition*, to enable comparison of the gaze activity. His galvanic skin response is measured with the amplification unit and a set of two electrodes covered in isotonic recording gel. His posture is recorded via depth camera and a motion tracking device composed of six infrared cameras paired with constellation of reflector spheres.

After the 20 seconds of passive stimulation, the designer is allowed to answer the questionnaire displayed on the mobile touch tablet. (cf. Figure 40) This is made so that the cognitive activity of answering the questionnaire does not interfere with the galvanic skin response and eye-tracking recording.

Between each stimulation and questionnaire phase, there is a relaxation phase of 60 seconds during which the stimulus is replaced by a neutral slightly off-white gradient. (cf. Figure 41) This is done in order to stabilize the emotional activity and flat line the galvanic skin response signal. However it can take 10 to 20 seconds longer for the participant galvanic skin activity to reduce to its regular fluctuation. In this case a longer resting time is granted until normal galvanic skin activity is recovered.

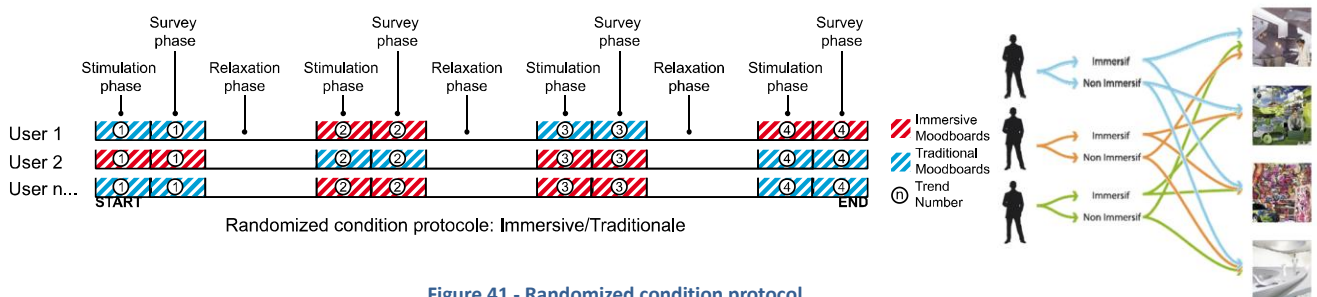


Figure 41 - Randomized condition protocol

Following this experimental procedure, at the end of EXP1, each moodboard has been seen 8 times in its traditional version and 8 times in its immersive version.

4.2.3.5 PILOT STUDIES.

4 moodboards are chosen out of a panel of 10 moodboards as stimulus materials. All moodboards are designed after a method inspired from Conjoint Trend Analysis (Bouchard C. , 1997). Each of them is composed of 6 to 10 distinct images. The moodboards are chosen by 8 PhD design students who are asked to grade how inspiring these trends are. Only the 6 moodboards that obtained the highest inspirational scores are kept. After this first step, a second selection is made in order to obtain four trends with no apparent kansei similarities, in order to acquire discrimination over styles, ambiance

and trends (cf. Figure 42).

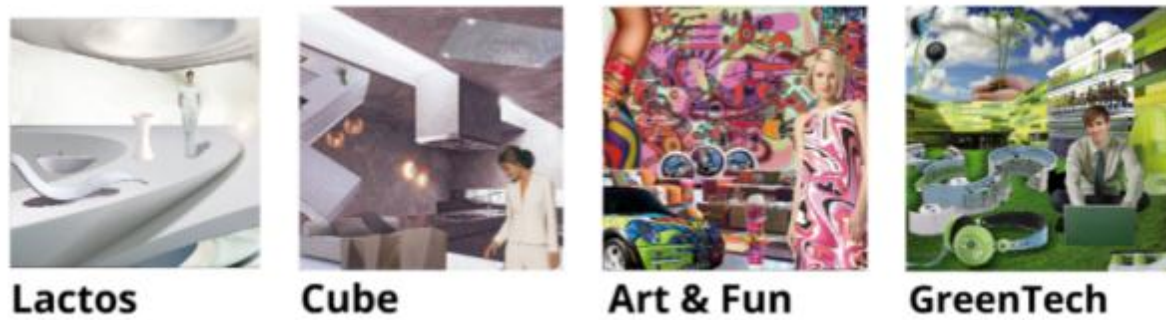


Figure 42 - Moodboards selected as stimulus for the experimentation

These moodboards are then transcribed into their immersive duplicate. This transcription is accurately executed, respecting the composition and proportions. The transcription is executed so that under a central motionless point of view the designer experiences the same visual perception under the immersive or *traditional condition*. Thus we create two comparable conditions: stimulation of the designer with *Traditional Moodboards (traditional moodboard)* in comparison to *Immersive Moodboard (immersive moodboard)*. One of the difficulties of this study is that we are studying a complex system in which a designer looks at a trend through a support. Deduction on causalities of a certain relationship between designer and trend can be unclear due to the fact that the subject, the object and the media are merged during the experiment. Theoretically, phenomenologists argue that the object of a representation and its support are condition of one another. Content separated from a support does not exist, nor does an independent support non-intended for content. Thus the experiment hereby performed, compares two indivisible relationships between users and contents through supports. (Husserl, 1990)

To design the semantic differential questionnaire the selected moodboards *Lactos*, *Cube*, *Art&Fun*, *GreenTech* are presented to 18 design students who are asked to freely describe them, using semantic descriptors. The collected 380 descriptors are then processed to extract the 9 most occurring descriptors per moodboard. These are used to design a list of 9 semantic differential scales per moodboard with which the stimulus moodboards are to be evaluated.

To design the emotional questionnaires the selected moodboards are presented to the same group of design students who are asked to mark out of a list of 306 emotional descriptors at least 3 relate to the way they feel about each of the 4 moodboards. The most occurring emotional descriptors are selected to compose an 8 one bound Likert scales with which the user can assess his emotional state.

The pilot tests are also useful to design a functional operating control station for the

experimentation. The combination of multiple measuring systems demands some pre-testing in order to eliminate the interference of a measure on one another.



Figure 43 – Virtual reality and experience measurement platform

To illustrate this point, some examples are listed below:

- The infrared lights generated by the optical tracking system can disable the eye tracking system which also runs with an infrared light.
- The user needs to be equipped with stereoscopic glasses. However these must not interfere with the head mounted camera filming the eye of the tested designer. For this matter we have used flat lensed polarized glasses so that the reflection they emitted didn't trick the eye tracking system into detecting them as an eye reflection.

4.2.4 RESULTS

In this section, based on the comparative quantitative and qualitative study protocol application, we identify what is the impact of the *immersive condition* on the moodboard experience and related kansei. The analyses of the results are summarized in the following subsections:

- **Physiological (ϕ):** comparison of galvanic skin response activity through analysis of emotional peak rate and intensity → §4.2.4.1
- **Cognitive (ψ):** comparison of the semantic and emotional profiles, of the valence and the intensity of the designers' emotional state → §4.2.4.2
- **Behavioral (β):** Study of the ocular activity & head position movement → §4.2.4.3
- **Physiologic/Cognitive (ϕ/ψ):** Data match between galvanic skin response activity and emotional questionnaire → §4.2.4.4
- **Physiologic/Behavioral (ϕ/β):** Emotional potential of individual objects, Non-interaction of physical activity on galvanic skin response measurements → §4.2.4.5

- **Cognitive/Behavioral (ψ/β):** Junction of emotional questionnaire data and behaviors in virtual reality → §4.2.4.6

4.2.4.1 PHYSIOLOGICAL (Φ): COMPARISON OF GALVANIC SKIN ACTIVITY THROUGH ANALYSIS OF EMOTIONAL PEAK RATE AND INTENSITY.

When analyzing the impact of virtual media on the emotional physiological response through galvanic skin activity, we took particular interest in two specific items: the rate at which a person emits a galvanic skin conductance peak (cf. Figure 44) and the normalized averaged intensity of the galvanic skin activity (cf. Figure 45).

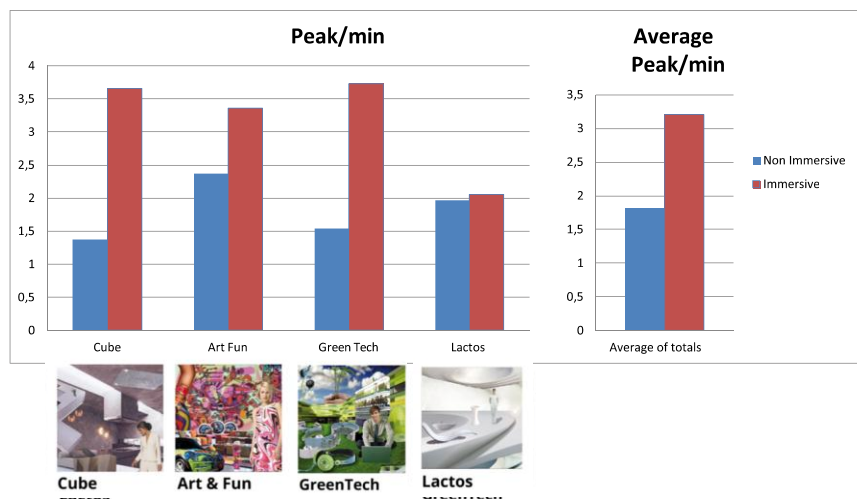


Figure 44 – Impact of spatialized immersive media on the average galvanic skin conductance peak rate

Only a rapid change in galvanic skin activity, larger than the largest difference in conductance fluctuation measured during relaxation phase was considered a peak. The peak rate shown in Figure 44 is the average frequency of galvanic skin conductance peak of designers facing the immersive (red) and traditional (blue) moodboard. We observe that the peak rate is much higher in three of the four moodboards comparisons. At the most, the difference of peak per minute is 2.2 points higher in *immersive condition* for the *Green-tech* moodboard. The peak augmentation phenomenon is less visible with the *Lactos* moodboard. This effect can be caused either by the lesser contrast in content, in color or in composition with regard to the other moodboards. However we still observe a major tendency for the peak rate to be higher when a designer is confronted within an *immersive moodboard*.

As for intensity in the galvanic skin activity, we have shown that the *immersive condition* induces a

higher intensity response. The comparison between the two curves displayed on Figure 45, express the same phenomenon than the peak frequency analysis, indicating a stronger physiological emotional response while virtually immersed.

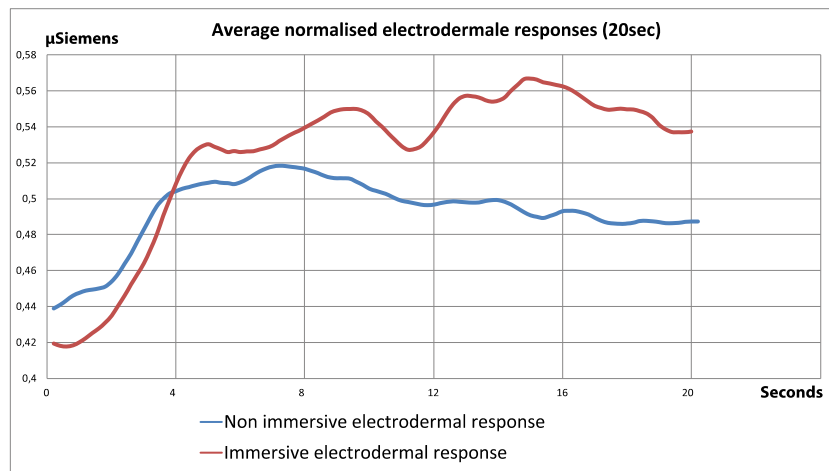


Figure 45 - Impact of spatialized immersive media on the average galvanic skin conductance peak rate

In summary, the findings from this quantitative study show that the physiological emotional activity of the industrial designer, based on his galvanic skin conductance peak intensity and frequency, is higher when the designer is immersed into moodboard rather than when he is facing an traditional moodboard. In terms of kansei, a trend conveyed by an immersive support induces a higher emotional impact than a traditional support.

4.2.4.2 COGNITIVE (Ψ): COMPARISON OF THE SEMANTIC AND EMOTIONAL PROFILES, OF THE VALENCE AND THE INTENSITY OF THE DESIGNERS' EMOTIONAL STATE.

When comparing the semantic profiles of the 2 types of moodboards, we focus on the specific terms which score differently when assessed in *immersive* or *traditional condition*. We also looked at variance related to the designer's answers, in order to understand if a certain media induces grouped or spread answers. First of all, on 40 pairs of descriptors (10/moodboard) we observe that only a fourth (20%) is significantly graded differently from *immersive moodboards* to *traditional moodboards* (cf. Figure 46). This indicates that both *immersive* and *traditional moodboards* are semantically evaluated by the designer as close. However we denote a few interesting differences. For instance the pairs *open/closed*; *aerated/confined*; *organized/disorganized* score differently from one condition to another and all refer to spatial attributes.

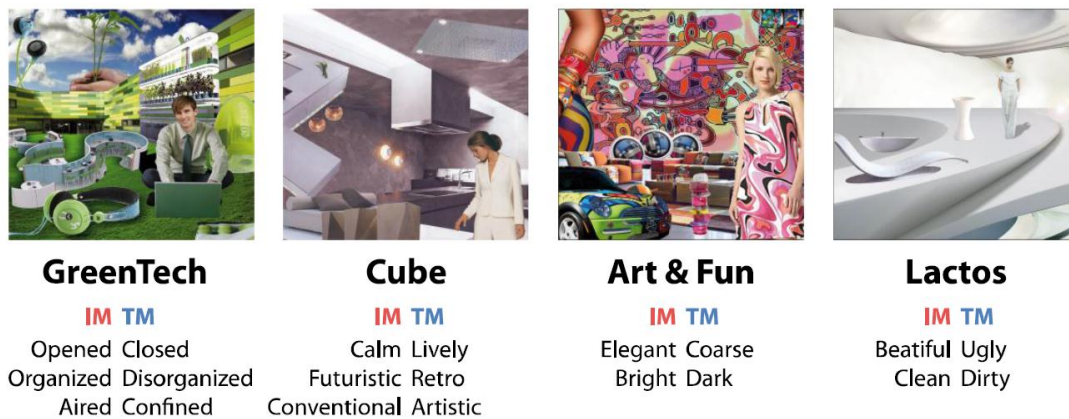


Figure 46 - Difference between Immersive moodboards & traditional moodboards semantic profiles

The *GreenTech* immersive moodboard appears to the designers as *open, aerated and organized* as the *traditional moodboard* is more *closed, confined and disorganized*. These semantic changes seem logical, as the spatial characteristics of a *traditional moodboard* are modified to produce an *immersive moodboard*. The ambiance and style communicated by the stimulus can also be affected. Still these differences are only on 10% of the total descriptor pairs. On average the variance of the designers' answers when referred to an *immersive moodboard* is 40% lower than when referred to a *traditional moodboard*. This strongly indicates that the potential of an *immersive moodboard* to communicate the same semantics to a group of people is higher than that of a *traditional moodboard*. In conclusion, these results show that the designers placed in immersive conditions perceive broadly similar semantics.

In the same way as with the semantic descriptors, we have observed how the immersive trend information impacts the way people assess their emotions with regard to traditional trends. The emotions terms are not presented with their opposites: emotional semantic terms are here proposed on a one bound scale. Thus when the designers give a score relative to the terms, we extract information not only on the emotions that are felt, but also on the intensity of their feelings. In a similar way, we extracted only the significant differences between the *immersive moodboard* and the *traditional moodboard* emotional profiles (cf. Figure 47). The results related to this questionnaire study are presented in the next section.

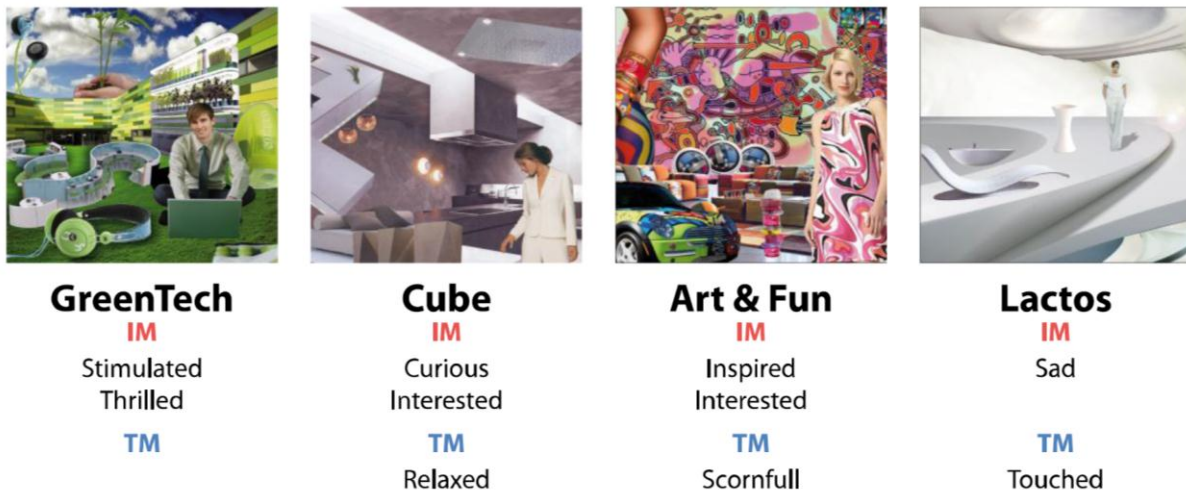


Figure 47 - Difference between Immersive moodboards & traditional moodboards emotional profiles

The overall phenomenon shows how more *attentive* the designers are when they are in front of an *immersive moodboard*. *Stimulation, thrill, curiosity, interest, inspiration* are remarkable virtues for an inspirational representation. Once again when using an *immersive moodboard*, the tool experience is better and more appropriate for the inspirational phases of the design process. The interactivity seems to focalize the attention through immersion and add playfulness and vividity. Seven out of 10 observed differences are in favor of the *immersive moodboard*, indicating that the *immersive condition* induces more intense emotions while appealing to the designers. When interrogated on the valence of their global emotional state, the designers qualified all the *immersive moodboard* as inducing a positive emotional state whereas two of the four *traditional moodboard* were qualified as negative: immersive spatialization and interactivity turned 2 emotionally negative trend experiences into emotionally positive experiences.

In summary the finding shown by the comparison of the semantic and emotional profile of the two types of moodboards carry two implications. First, the transcription of a traditional to an immersive trend only scarcely modifies the semantic profile of a trend. Secondly, we observe that the immersion tends to stimulate a positive emotional state and rather interested states for an inspirational medium such as *curiosity, interest and thrill...* These are assets to early design tools such as moodboards. These results show that the designer is increasingly emotionally engaged into the immersive moodboard.

4.2.4.3 BEHAVIORAL (B): STUDY OF THE OCULAR ACTIVITY. & MOVEMENT

The next result concerns the study of the ocular behavior. It enables the precise timewise depiction of

what a participant is looking at. Thus it gives information on the time each objects composing the moodboards has been looked at. This allows the comparison of visual exploratory behaviors in both immersive and traditional conditions.

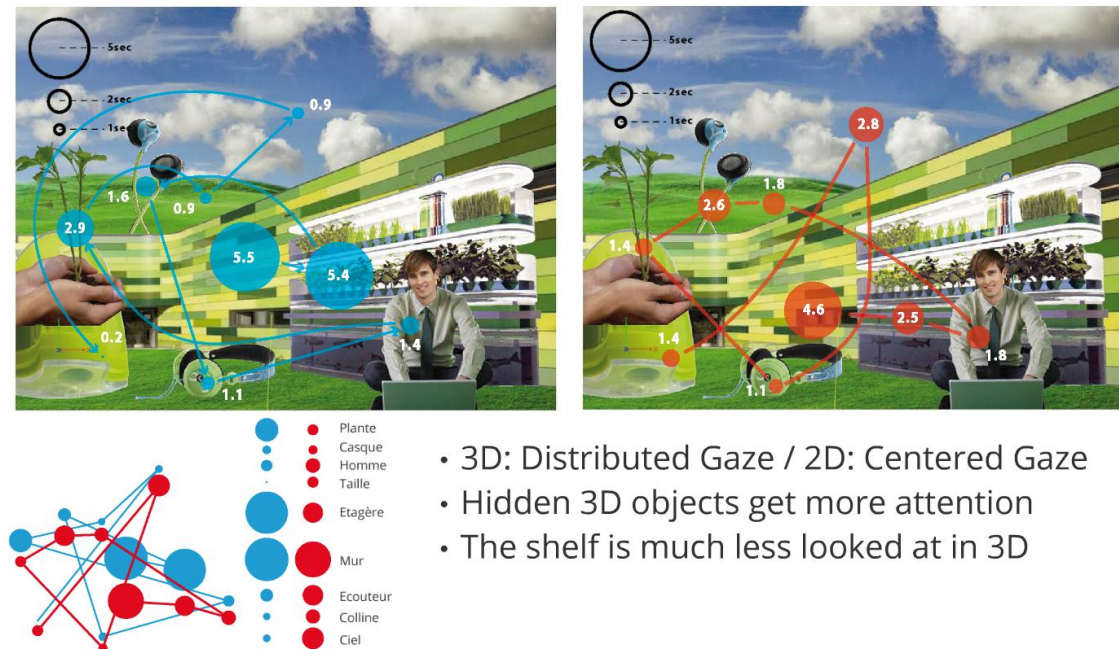


Figure 48 – Example of Ocular data comparison: critical trajectories & total time/object

It is important to understand that in the *immersive moodboard* it is possible to see what in *traditional moodboard* would have been occluded (cf. Figure 32). The overall area of a visual is thus bigger than that of a *traditional moodboard*. By moving in the interaction space the designers have access are able to confront two objects that wouldn't have been close in a *traditional moodboard*. The first behavioral difference we observe is that the designers have a tendency to distribute their gaze when in *immersive condition* (cf. Figure 48). The immersive space is visually apprehended in a more global and holistic way. This is confirmed by the time-per-object measure which indicates how long a designer looks at a particular object with regard to its size. This study shows that designers spend more time looking at a small number of objects when they are placed in the *traditional condition*. The moodboard is a stylistic space created with a high coherence between the objects it is composed with. Thus a media inducing a global approach to style representation should enable a good assessment of the trend as a global ambiance and stress the overall meaning of the represented trend.

4.2.4.4 PHYSIOLOGIC/COGNITIVE (Φ/Ψ): DATA MATCHES BETWEEN GALVANIC SKIN ACTIVITY AND EMOTIONAL QUESTIONNAIRE.

Psychological emotional survey	Physiological measures
<ul style="list-style-type: none"> Higher intensity of 83% of emotional terms score in <i>immersive moodboard</i> compared to <i>traditional moodboard</i>. Higher global emotional impact of <i>immersive moodboard</i> than that of <i>traditional moodboard</i>. Better global valence of emotional impact of <i>immersive moodboard</i> with regard to <i>traditional moodboard</i>. 	<ul style="list-style-type: none"> Higher intensity of physiological emotional response in <i>immersive moodboard</i> than in <i>traditional moodboard</i> Higher physiological emotional peaks frequencies in <i>immersive moodboard</i> with regard to <i>traditional moodboard</i>.

Table 2 – Recapitulative table of data matches between galvanic skin activity and emotional questionnaire

Physiological measures and cognitive measures match to show that the emotional impact of a trend is higher when it is spatialized (cf. Table 2). The designers express themselves as being *stimulated*, *thrilled*, and *interested*. This settles the fact that their experience is intense and that the design is increasingly emotionally engaged into the immersive moodboard.

4.2.4.5 PHYSIOLOGICAL/BEHAVIORAL (Φ/B): EMOTIONAL IMPACT OF INDIVIDUAL OBJECTS, EFFECT PHYSICAL ACTIVITY ON GALVANIC SKIN MEASUREMENTS.

By combining galvanic skin response and ocular data, we can point out what specific objects are looked at when a galvanic skin conductance peak is produced by a designer. On Figure 49 is a sample measured on a designer while observing the *GreenTech* moodboard. The physiological response to the 4 moodboards is clearly visible in form of groups of peaks. It is also possible to see the stabilization phases during which the designer is shown a white static image. The red dots correspond to the designer's gaze, caught by a head camera during a galvanic skin peak.

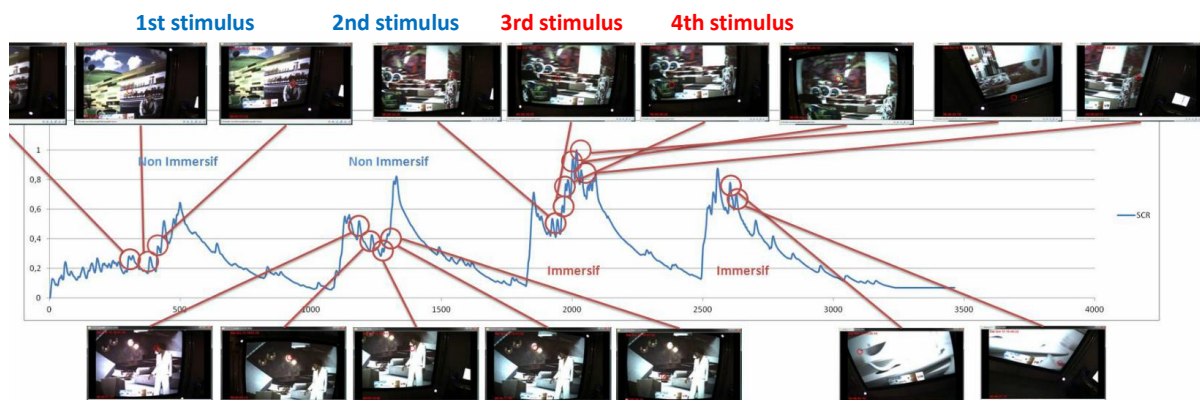


Figure 49 - Example of gaze position and galvanic skin response peak combinatory analysis

This combination of measures shows that the physiological emotional reaction during inspiration process enables us to track a peak back to a single object in the moodboard composition. By linking peaks to objects it is possible to describe the propensity of an object to generate the highest galvanic skin conductance peak emitted during an individual stimulation.

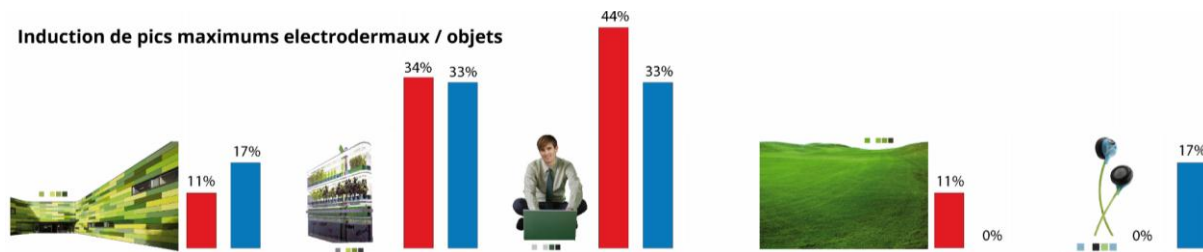


Figure 50 - Propensity of maximum peak induction per object depending on media

For instance we observe that the human figure and the shelf have a tendency to generate high intensity peak on the *GreenTech* moodboard whether in *immersive* or *traditional* condition (cf. Figure 50). For practical reasons we only show the *GreenTech* bar-graph, however the human figures are top peak inductors in all the tested moodboards. The emotional resonance between moodboard and the industrial designer is crucial during the inspiration phase. These results show that the highest emotional inductor is a human figure.

4.2.4.6 COGNITIVE/BEHAVIORAL (Ψ/B): JUNCTION OF EMOTIONAL QUESTIONNAIRE DATA AND BEHAVIORS IN VIRTUAL REALITY

We have identified a very common behavior induced by the immersive spatialization of data. By looking at the collected gaze and head position data, we find that the designers try looking behind objects and try to find the spatial limit of the virtual environment. This exploratory behavior resonates with how the designers evaluated themselves: *curious and interested*. The designers said themselves more *thrilled* and *stimulated* in *immersive moodboard*; it resonates behaviorally with their head movement quantity, which is much higher in *immersive moodboard*. *Curiosity, stimulation, excitement and interest* are all manifested during visual interaction, by body movements, such as gaze and changes of head position.

4.2.5 DISCUSSION

By adding depth to the moodboard we observe a series of changes in the designer/moodboard relationship (cf. Figure 51). These changes related to kansei are summed up in the next scheme.

Immersive moodboards induce:

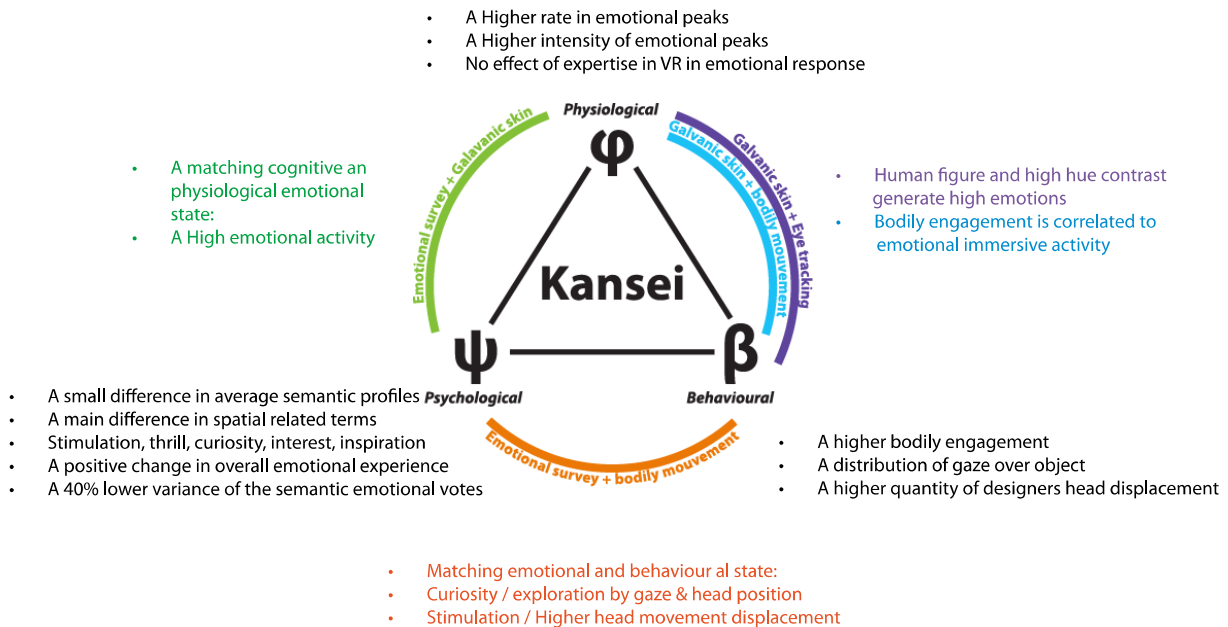


Figure 51 - Results and findings

This comparative study observes how a designer reacts when he is given inspirational trends information through an original structure: a spatial immersive moodboard. To record the kansei dimension related to the immersive moodboards and to the related designer's experience, the design activity is studied through simple contact between trend information and the designer. We thus record and analyze the kansei related to a designer looking at a trend and not a designer using a trend as a basis for a conceptual proposition. Nonetheless the participants are trained designers who are asked to retrospectively contextualize the immersive moodboards with their activity.

The results of the analysis revealed four major improvements that may impact the design process. The process benefits in different ways from our system and new methodology. The upcoming paragraph lists the scientific contribution of our research and details the impact it has on the design process. Using digital trend environment enables data capitalization, reproducibility and structural & parameter modularity.

- Capitalization data base: Every immersive moodboard is recorded and compiled in an immersive trend database.

- Reproducibility: Immersive moodboards are datasets that can be experienced / duplicated on any basic immersive system.
- Structural & Parameter modularity: Moodboards can be modified, reused and revised as the digital support enables a quick modification of the overall ambiance (fog, color filters...) or of individual image (position, photo editing...)
- Spatial immersive workflow: The immersive moodboards are a first step towards a spatial immersive early industrial design workspace.

The clearest effect observed is the emotional increase triggered by the interactive relationship between the designer and the moodboard. As an early representation, the immersive moodboard is an externalization of an ambiance. By externalizing the ambiance, the designer is able to experience the induced emotions. Thus he can understand and emotionally assess his work, involving the emotional processes in the aesthetic judgment.

Even before having given body to the product, the immersive moodboards tool validates guidelines and gives guaranties of design trails and design hypothesis. Augmenting the communication canal between the designer and his trend externalizations extends the fidelity of the designer's decisions through a better dialogue with his representation.

To obtain a valid evaluation of a trend, the immersive system deludes the brain into thinking it is in a reality. The immersive moodboards are intended to lead the designer into enacting with a virtual universe. When using a traditional moodboard, the designer is supposed to project himself in the ambiance he has created. Our immersive system liberates the designer from this effort by projecting his consciousness in the moodboard through bodily engagement, giving a vivid feel of the trend represented. Exploring the immersive moodboards with one's body gives credibility to the early representation. The more credible the trend seems, the more truthful the judgments and style decision will be. The enactive link between consciousness, body, reality and ambiance serves the design process in trend perception and thus evaluation.

It is interesting to see that modifying the support of the trend information only modifies how the designer attributes specific semantics and emotion descriptors to a trend. Our research has shown that the meaning communicated by a traditional moodboard and its immersive homologue differ on semantic terms related to spatial description. Furthermore we have measured that variance between the semantic profiles of immersive moodboards are 40% lower than that in the case of the traditional moodboards. This indicates that spatialized virtual environment, as a support for trend information, prevents the semantic erosion inherent to the transition of a message from one support (moodboard)

to another (designer). Using this tool will provide similar understanding and feel of the design context, similar mental representation anchors, and formal vocabulary basis. Thus it guarantees cohesion of the design team on the vision of the project.

With the right technological platform, an immersive moodboard is as simple to design as a traditional moodboard. The time investment is slightly increased (+20minutes) since the third dimension adds to the complexity of the construction. However the raw material used to generate a traditional moodboard and an immersive moodboard are similar. The increasing development of three-dimensional ready hardware will soon enable this tool to enter design studios through lighter support than a wall. A few prototypes of 3D touch tablets are already in development worldwide and will surely suit the designer's needs.

As a support for the sketching phase, the abstraction in moodboards must be significant in order to yield innovative concepts during the generation phase. They must question rather than answer the brief. The immersive moodboard is composed of images coming from very different sources (Internet data bases, design magazines, photographs...). Even though these images are close in style, their differences give a surrealist feel to the overall composition. This fuzziness opens the possible solution space and engages the designer to breach the design gap.

4.2.6 LIMITATIONS OF CURRENT METHODS

The limitations of EXP1 are the following:

- Contextualized moodboards

In EXP1, the moodboard is not used in a design context but rather more as a simple visual/immersive stimulus. One might argue that a moodboard evaluated out of its context is only partially evaluated. Our approach positions EXP1 as a probe in early immersive representations of the trend. Thus it is necessary for EXP2 to explore further and extend the boundaries of the tested processes to a complete early design activity ranging from design brief to concept evaluation. The tested process in EXP2 integrates the use of an immersive and a traditional moodboard as an inspirational material.

- Effect of measure on measured system

As shown in Figure 99 on page 164, the user experience measurement platform is composed of large measurement devices. The devices can be invasive and occult the natural physiological, psychological

and behavioral responses. One of our object of study, the emotion, is a fragile concept that can be influenced by a large number of changes in the participant's environments. For instance, the participant's consciousness by itself can disturb the measurement of the natural emotional state of the participant. (Compton Effect). It is problematic to identify and measure the impact of the experimental setup on the participant's emotional state. For this reason the full equipment was only kept for approximately 6 minutes during EXP1. The second experimentation EXP2 does not integrate the full user experience measurement material for the participant's tasks lasts 50 minutes longer than in EXP1.

- Intra or inter-personal comparison dilemma

Upon evaluating the impact of the immersive medium on the kansei related to a moodboard, two opposed methods are available. The first aims at comparing the impact of the same moodboard in immersive condition and traditional condition on the same participant. Thus this technique compares the intrapersonal experience of a traditional and an immersive moodboard. However, this method implies that the participant has consumed and memorized the experience of the stimulus in a first condition when he is stimulated by the second condition. The impact of memory on the evaluation of the moodboard experience renders the results hard to interpret. The second method proposes to show the stimulus in a given condition to a participant and in the other condition to another. Thus the memorization of the stimulus is not problematic because the comparison is interpersonal. However, this method suggests repeating this trial on homogeneous population in order to be able to analyze the effect of the condition on the experience. The complexity of dealing with memory has oriented our study to apply the second interpersonal method.

4.2.7 CONCLUSION OF THE COMPARATIVE STUDY OF IMMERSIVE AND TRADITIONAL MOODBOARDS

The immersive moodboard application is one more application added to the digital design workflow developed by the New Product Design Laboratory. This experiment provides a better understanding of how kansei identification can be augmented by virtual reality techniques during early design activity. Through the exploration and the inspiration phases, the designer works on the kansei dimension to predict the future impact of the product. Rendering the moodboard immersive and immersing the industrial designer very soon in early representations has proven to be impactful and to augment the bodily and emotional engagement of the designer. The immersive moodboard is an early opportunity to test and fine tune the desired emotional impact of the future final product. In so far as a moodboard is shared within the design studio, the immersive moodboards are a media that causes the designer to consider the inspirational space with a holistic and coherent vision. This holistic point of view enables the design team to share the same references as a project starting point. By combining the reality of the designer in inspirational phase and that of a set of trend data, the confrontation is inevitable and the designer is experiencing the moodboard as a plausible reality. This confrontation gives him access to the kansei related to the future product. The interactivity gives access to stimulating and engaging design environments. Acting as an intermediate representation, the immersive moodboard increases some characteristics of the traditional moodboards. These characteristics are the ability to impact, stimulate, thrill, to trigger curiosity, interest and to inspire the designer. This induced state of mind seems to correspond with the design exploration and questioning inherent to early design process. Having a vivid representation of the kansei references to the product design project forces the designer to profoundly confront himself with the environment, ambiance and the design ground he has to work with. The immersive moodboards provide an editable reality enabling the exploration of style and its effects. The emotional activity of an industrial designer during the inspirational and generative act, impacts his production. Rather than focusing the design process on the end-user only, we have developed tools and methods which take in account the industrial designer himself. This research work changes the future paradigms from a user-centered design to a user and designer-centered design. We believe that immersion is a lever towards an attractive, engaging and efficient design process.

The results in EXP1 validate the appeal of the participants for designer centered tools and our results show that spatial immersive environments are a productive trail to engage the design in a high

emotional activity. The first experiment acts as a probe for more complex interactions and deeper exploration of the digitalization of the early design process. EXP2 expands the scope of our research to a spatial immersive process composed of an inspiration phase, a concept generation phase and a concept validation phase.

4.3 EXP 2: COMPARISON BETWEEN AN IMMERSIVE DESIGN WORKFLOW AND A TRADITIONAL DESIGN WORKFLOW

This second experimentation is an empirical study aimed to answer HYP2: *The emotional activity during early design and the concepts which are the product of this activity are modified by a transposition of the traditional early design workflow into a spatial immersive workflow.* EXP1 will be presented along this plan:

- Context → § 4.3.1
- Objectives → § 4.3.2
- Method → § 4.3.3
- Results → § 4.3.4
- Discussion → § 4.3.5
- Conclusion → § 4.3.7

4.3.1 CONTEXT

Our first experimentation shows that rendering the industrial designers' early tools and workspace immersive, increases his emotional activity during his inspirational process. The designer shows empathy and great interest towards the immersive moodboards. In EXP2, in addition to the development of immersive moodboards, we establish immersion in the sketching activity for concept generation. To this end, we developed an immersive sketching tool in order to better test in EXP2 the entire immersive early design process.

We have built the EXP2 with regard to the first experimentation. Because the involved professional designers show a positive response to the immersive moodboards, we have decided to extend the experiment to the whole early design process including inspiration, concept generation and evaluation phases, in EXP2.

. The implemented measures are also reduced, as the duration of the EXP2 is longer and the activity of the user is far more intense than in EXP1.

EXP 2 is dependent upon HYP 2. This experimentation aims to identify the effect of an immersive industrial designer's workspace on his emotional activity. Other effects are studied, such as the quality of the design concept they produce and the impact that the concepts induce on potential

end-users.

We lead the study on the basis of a comparative protocol confronting two groups of 14 professional designers. One group employs traditional tools such as a two dimensional moodboard, and traditional sketching. The other group uses an immersive moodboard and the immersive sketching application.

4.3.2 OBJECTIVES

The overall goal of this study is to understand how spatial immersive early design tools can be a vector for emotional design and help the designer to express his intention to the end-user. In addition, the aim of EXP2 is to explore the impact on a complete early immersive design process ranging from design brief to concept proposition (cf. Figure 52). The inherent spatial immersive nature of the design activity leads us to expect that a spatial workflow is better adapted to the overall design practice. Moreover, a spatialized immersive process may engage and stimulate emotional activity during the generation phase as it does during the inspiration phase.

The 3 objectives related to EXP2 are the following:

- The first objective is to compare the emotional activity of a group of industrial designers using early design traditional tools with the emotional activity of a group of industrial designer engaged in early design with spatial immersive tools.
- The second objective is to understand how the *aesthetics, originality and intelligibility* of concepts designed in immersive early workflow, differ from that of concepts designer using traditional early workflow, when assessed by end-users.
- The third objective is to appreciate if the immersive workflow is a better vector to support the semantic - emotional link between the designer and the end-user, than a traditional workflow.

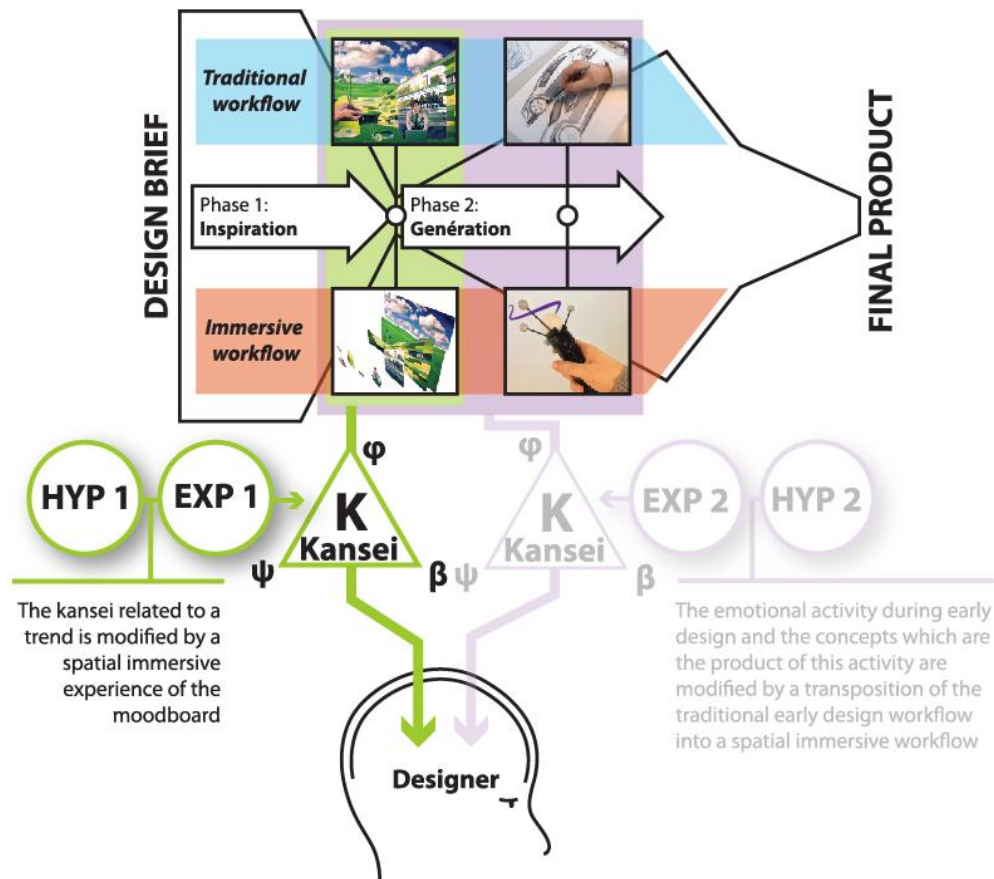


Figure 52 – Position and structure of the EXP2

4.3.3 METHOD

EXP2 is designed to compare the activity of traditional early design with the activity of immersive early design. In order to thoroughly evaluate how the early design process can be augmented by the immersive spatialization of the industrial design workspace, we chose to compare the activity and outcomes of two groups of designers placed into two different conditions. Each of the designers, in practicing either the *immersive workflow* or the *traditional workflow*, is individually given the same design brief and is required to produce one design concept. However, one of the groups is given a set of traditional tools whereas the other group receives immersive tools to complete their tasks. The tools used by the designers in *immersive condition* are a spatial immersive version of the traditional tools, but these immersive tools have been downgraded so that they carry the same theoretical functions. (cf. Figure 53) This enables the objective comparison of both externalization processes.

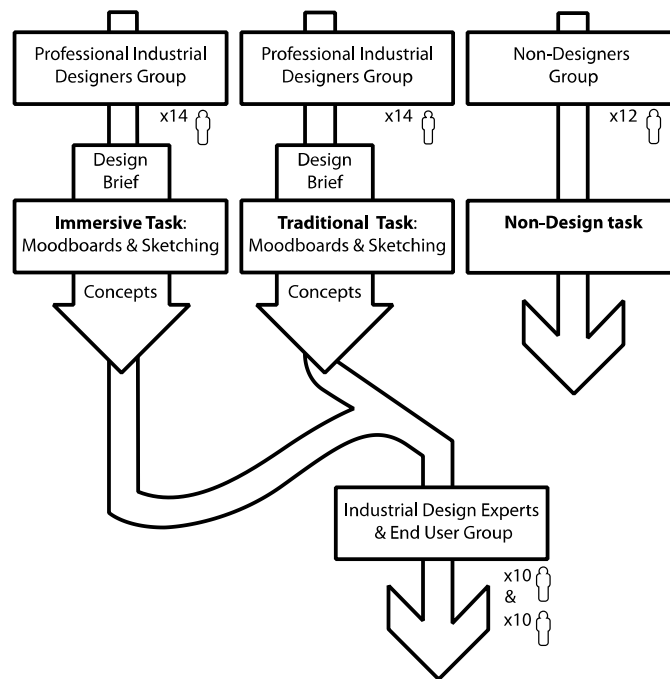


Figure 53 - Macro structure of experimental study (essential protocol?)

We are willing to observe the designers engaged into a sequential work, operating with the inspirational and generational tools that are given to them. Their production is then analyzed by submitting it to the judgment of a group of experts and another group of end-users (cf. Figure 54). A common coding scheme is developed in order to objectively compare the sketches issued from the traditional and from the immersive activities. We monitor the physiological, psychological and behavioral data of the designers during their inspiration and creation activity. The galvanic skin activity is recorded throughout the design task, enabling us to identify the time frames during which the designers have an intense emotional activity. Thus by combining the video activity coding and the recording of the designers' galvanic skin response, it is possible to characterize the emotional value of a type of activity. Once the design activity ends, the participants are given a last questionnaire planned to collect post experience comments. The purpose of the group in *traditional condition*, as a control group, is to serve as referents to compare the immersive early design activity to the early traditional design activity. The non-designers group enables us to qualify the skills of the designers group and observe potential difference in the praxis of our innovative tool. By involving non-designer in the immersive experience, we also collect data from a random population in order to qualify possible uses outside of the scope of design.

4.3.3.1 PARTICIPANTS

The total population partaking in this experiment counts 65 subjects. 28 are professional designers involved in an immersive (ID) or a traditional design task (TD) (cf. Figure 55). 10 are product end-users (EU), they judge the design concepts outputted from the design task. 10 are master designers (MD), who are asked to evaluate the inspiration level between sketch and moodboard. This group is composed of professional designers and design professors with more than 15 year of design practice. 11 are non-designers (ND), simply acting as design neophytes, and 6 art professors (AP). This repartition is illustrated in the next figure.

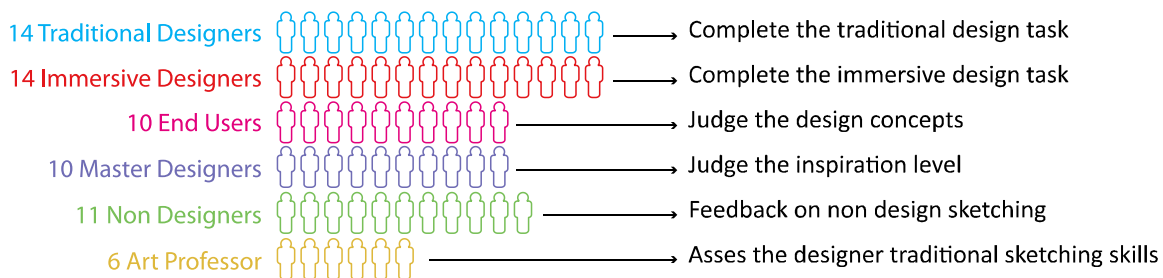


Figure 54 – Populations groups involved in EXP2

64% of the designers are men and 36% women: this repartition is representative of the professional French design landscape (Lieu du design, 2010). The male participants are majorly comprised in a category of 25 to 31 years old, and the women belong to a ranging of age from 41 to 45. All of the twenty eight designers are professional designers working in the Paris area. The majority of the tested population (70%) has a design experience raging from 5 to 20 years. 86% of the participants have a stereoacuity over the clinical normal value (40° seconds of arc). 10% of the designers are left handed.

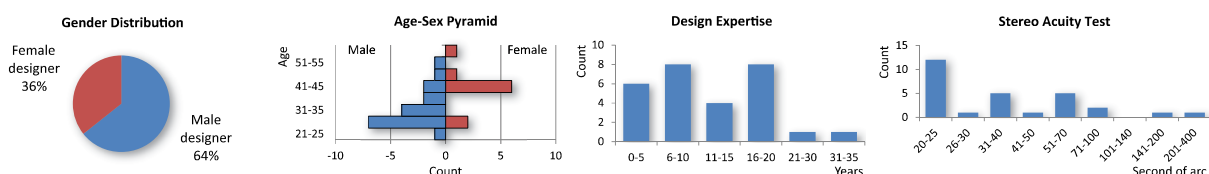


Figure 55 - Description of the designer population involved in EXP2

A wide range of profile has been chosen to evaluate the immersive early design activity and concepts in order to capture subtle relationship. For instance, the product end-users express their point view when asked to evaluate the concepts. Ultimately the end-user's appreciation of the product is the most important relationship, for he handles the largest part of the product lifecycle. However, the expert designer is better empowered by his knowledge and years of practice to judge the

performance of a design process and of the designer's aptitude to take a brief into account and correctly respond to it. The art professor has been chosen for his knowledge of the representation tool and because he is very often brought to judging sketches.

The designers participating in the design task all have skills related to the traditional tools set and years of practice in design. However, all of them discover the immersive early design tools for the first time, as they partake in the experimentation. This suggests that they are experts in traditional design but novice in immersive design. This will be discussed in experimental requirements section (4.3.3.3).

4.3.3.2 EQUIPMENT

The experiment is available on the virtual reality platform of the New Product and Innovation Laboratory (NPDIL), which is divided into two spaces. The first is attributed to designers in *traditional condition* and the second to designers in *immersive conditions*. The platform is confined and user stimulation is fully mastered so that no bias can disturb the ongoing experiment. The following figures explain the setup of the experimentation.

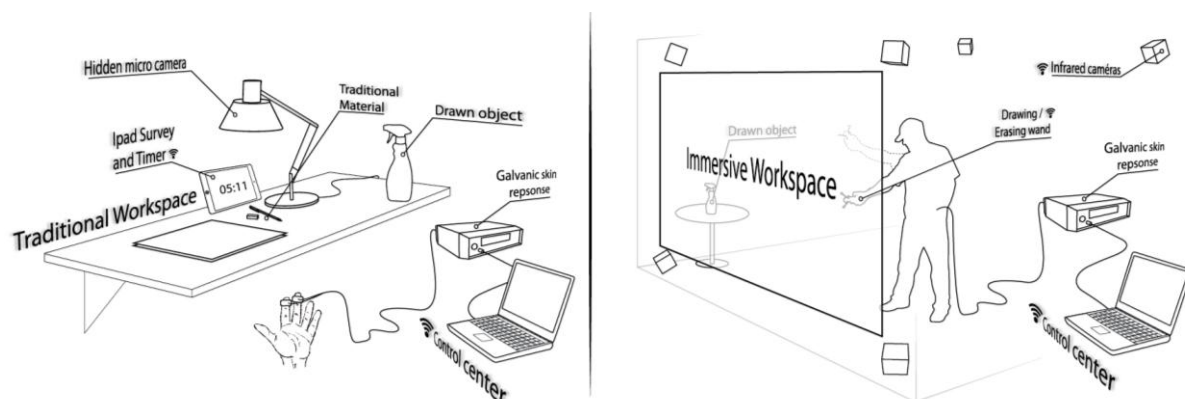


Figure 56 - Experimental set-up for immersive and traditional design workflow

Traditional condition equipment	Immersive condition equipment
Paper	Virtual pen
Mechanical Pencil	
Rubber	
Moodboard (Cube)	Immersive moodboard (Cube)
Video camera	Virtual camera
Lampe	Control center
Object to be copied	
Automated Timer	
Touch tablet	

To perform the task of sketching in an immersive space, the subject is holding a control device with several command buttons in his dominant hand. An optical tracking system follows the user's hand

and head movements. To track these movements, the device is equipped with 6 infrared cameras (Optitrack S250e). The global latency of our immersive system is measured from the user's movement to the visual end to end delay. This delay ranges from 32ms to 48ms, depending on the processors load of the immersive device. To estimate this delay, we measured directly the gap between the real and virtual pen tip at a constant given speed (1m / s).

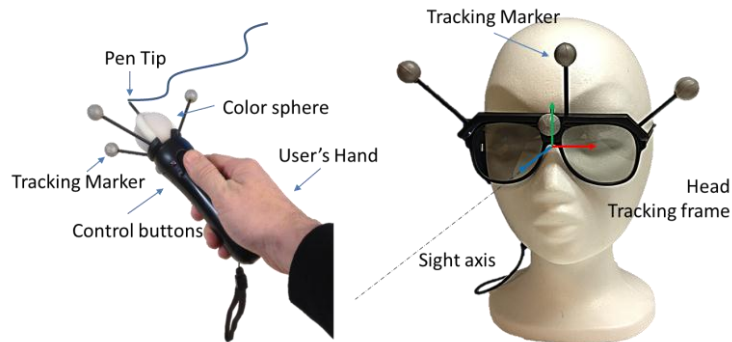


Figure 57 - Participants gear

The pen tip is 5cm from the center of the lighting sphere on the top of the remote control device. The virtual pen tip is shown by a virtual dot and the real pen tip is shown by a spike clipped on the light sphere (cf. Figure 57). The experiment is entirely recorded through audio and video systems.

4.3.3.3 EXPERIMENTAL REQUIREMENTS

In a concern for thorough results, we identify two factors susceptible of impacting the use of the immersive early design tools. This situation requires that we eliminate these factors as being the cause of the established effects.

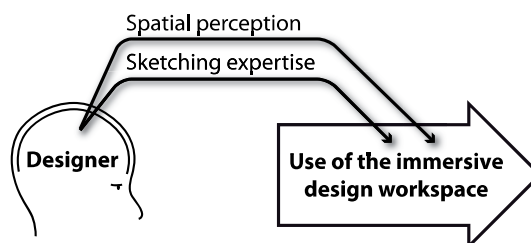


Figure 58- Impact of sketching expertise and spatial perception on the use of immersive early design workspaces

We identify spatial perception and traditional drawing expertise as in-built ability of the designers likely to have an impact on the immersive design activity (cf. Figure 58).

- To guarantee that the effects observed are due to the immersive/traditional condition and

not to an intrapersonal variation of spatial perception, we undertake to measure the spatial perception of the groups of designers in immersive or traditional condition. These measures are undertaken by using a Mental Rotation Test (Johnson 1990). The measurement procedure is detailed in the paragraph explaining the experimental preliminary task – sub-task 1 (cf. §4.3.3.4.1.1).

- The second factor identified as having a potential effect on spatial immersive drawing is skill in traditional drawing. In order to verify this experimental requirement, we compare the traditional sketching skill of the designers to their sketching skill while in immersive conditions. The measurement procedure is detailed in the paragraph explaining the experimental preliminary task – sub-task 2&5 (cf. §4.3.3.4.1.1).

4.3.3.4 PROCEDURE

The procedure of this experiment is semi-automated. In this way the system drives the participant through all the *sub-tasks*. The participant is first welcomed on the virtual platform by the experimenter who presents the overall process of the experiment. He is then requested to authorize the capture of his physiological, psychological and behavioral data, the use of these data and the anonymous publication by the research team of the NPDIL. This authorization is signed on a paper contract. The protocol of this experiment engages five groups of participants into different sequential task. The experiment requires two segments. The first segment takes place in the laboratory which hosts the compared immersive and traditional early design processes. The second segment of the experiment is composed of online questionnaires.

The participant scarcely interacts with the experimenter. Throughout the experimental procedure, an audio-guide first explains a task to the participant, who then can complete the task. Either a timer (§ 4.3.3.4.1.1 *Sub-task 1, 2, 5*) or the participants ends the task, which automatically triggers the explanation of the next task. At the beginning of the experiment, the participant is encouraged to follow the instruction given by the audio-guide rather than asking the experimenter. This helps in reducing the contact between experimenter and participant, reducing at the same time any bias due to social/emotional interaction. This experimental device also gives each participant the same amount of information. The experimenter only intervenes to mediate any misunderstanding, or answer critical questions. A FAQ has been prepared during pretests so that any question collects the same answer. Participants are told at the beginning that the question will be turned down and answered at the end of the experimentation. As the emotional state is a delicate object, a maximal

isolation of the experimental process is necessary to obtain the throughout results. All stimulus and surveys questions are submitted to the participants in a randomly order.

The experimental procedure is divided into two segments. The first segment is an in-laboratory experiment during which the designers are welcome to execute 4 tasks:

1. **The preliminary task** is designed to collect data in order to contextualize the *early design task*
2. **The early design task** is intended to position the participant in an immersive or a traditional early design situation
3. **The experience feedback task** is aimed at collecting feedback from the participant on his immersive design experience.

The Second segment is an online questionnaire composed of a single task:

4. **The Copy-sketch & Concept evaluation task** is primarily intended to evaluate the outcomes of the early design task.

The next figure gives an overview of the different tasks taking place in both segments of the experiment and of the Sub-tasks composing those tasks (cf. Figure 59). This figure is followed by two tables, each detailing the Sub-tasks. (cf. Table 3 & Table 4)

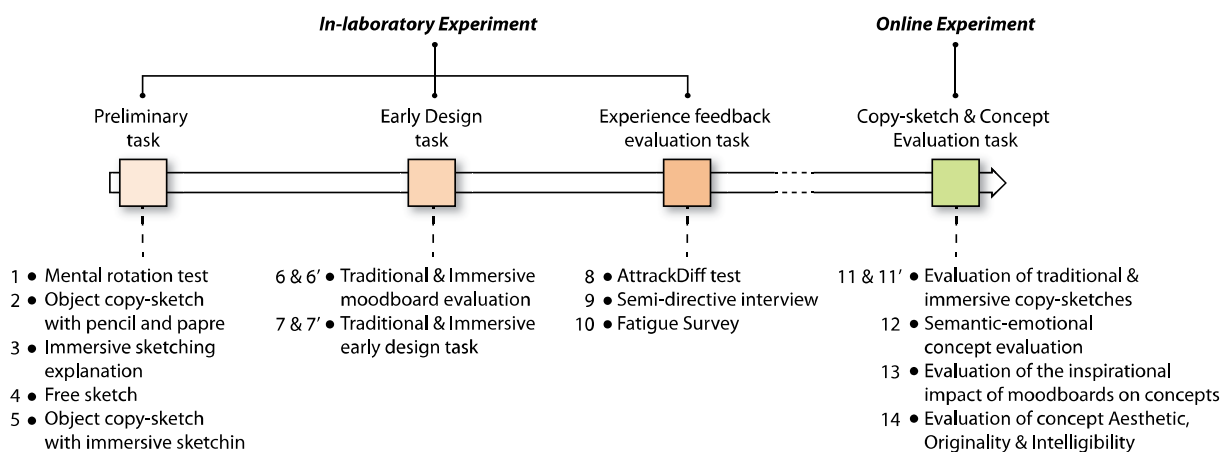


Figure 59 - Tasks distribution over the experimental procedure

The next two tables detail the architecture of the experimental procedure. This list displays the procedure on 5 levels:

Task – Subtask – Description – Participants – Time frame

Task	Sub-task		Description	Participants			Time frame (min)
				Designers in immersive condition	Designers in traditional condition	Non designers	
Task 1 Preliminary task §.4.3.3.4.1.1	1	Mental Rotation Test	Evaluation of participants spatial objects	X	X	X	6
	2	Object Copy-Sketch with pencil & paper	Evaluation of the participants Traditional copy-sketch	X	X		6
	3	Immersive Sketching Explanation	Demonstration of Immersive sketching	X	X	X	3
	4	Free Sketch	Simple shape drawing and experience discovery	X	X	X	10 to 15
	5	Object Copy-Sketch with Immersive sketch	Evaluation of the participants Immersive copy-sketch	X	X	X	6
Task 2 Early design task §.4.3.3.4.1.2	6	Semi	Participants evaluate the traditional or Immersive moodboard with semantic/emotional questionnaires		X		5
	6'	Semantic-emotional Immersive Moodboard Evaluation		X			5
	7	Traditional Early Design Task	Participants design and object using the traditional or Immersive workflow		X		20 max
	7'	Immersive Early Design Task		X			20 max
Task 3 Experience feedback evaluation task §.4.3.3.4.1.3	8	Attrakdiff	Participants complete the Attrakdiff questionnaire	X	X		5
	9	Semi-directed Interview	Participants complete the Experience Feedback Survey	X	X	X	5 to 10
	10	Fatigue Survey	Evaluation of Visual, physical and global fatigue of the participants	X	X	X	1
End §.4.3.3.4.1.3		End	End of in-laboratory experiment				

Table 3 - In-laboratory experimental procedure

Task	Sub-task		Description	Participants		
				Master designer	Art Professor	End-user
Task 4 Copy-sketch and Concept evaluation task	11 & 11'	Evaluation of the traditional sketches of copied objects	Participants evaluate the traditional sketching ability of the designers copy sketches (Sub-task 2)		X	
		Evaluation of the immersive sketches of copied objects	Participants evaluate the immersive sketching ability of the designers copy sketches (Sub-task 5)		X	
	12	Semantic-Emotional concept evaluation	Participants evaluate the semantic/emotional profile of the concepts			X

§.4.3.3.4.2	13	Evaluation of the moodboard inspirational impact on concepts	Participants evaluate the extent to which the concepts reflect the moodboard	X		
	14	Aesthetic, Originality & Intelligibility Concept Evaluation	Participants evaluate the aesthetic, originality & intelligibility of the concepts			X
End		End	End of online experiment			

Table 4 - Online experimental procedure

4.3.3.4.1 IN-LABORATORY EXPERIMENTAL PROCEDURE

The in-laboratory test procedure is divided into 3 types of task: The *preliminary task* (§.4.3.3.4.1.1), the *Early design task* (§.4.3.3.4.1.2) and the *Experience feedback task* (§.4.3.3.4.1.3). (cf. Figure 60)

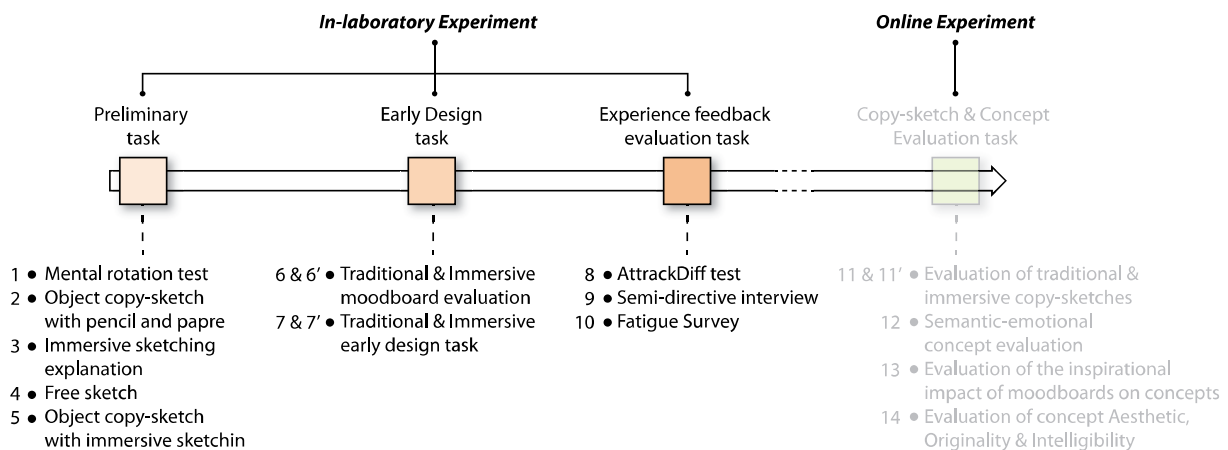


Figure 60 – In-laboratory task distribution

All participants are required to give their full name, genre, contact and age. Factors like dominant hand, ocular correction, and design expertise are also collected. The participants also complete a stereo acuity test with the Randot® Stereotest from Stereo Optical®. During this Sub-task, morphological parameters of the users' visual system (eye gap and position to infrared tracker) are also inputted in the virtual device to guaranty a good immersive perception. The participants are also required to describe the substances that they might have absorbed 2 hours before the experiment in order to validate their eligibility for the upcoming tests. Substances like caffeine or nicotine can have drastic effects on the parasympathetic system and affect the physiological emotional response. This sub-task ensures that all participants are fit for the experiment and have stood by their non-consumption commitment.

4.3.3.4.1.1 PRELIMINARY TASK

- **Sub-task 1:** Mental rotation test (ID, TD, ND) 6 minutes

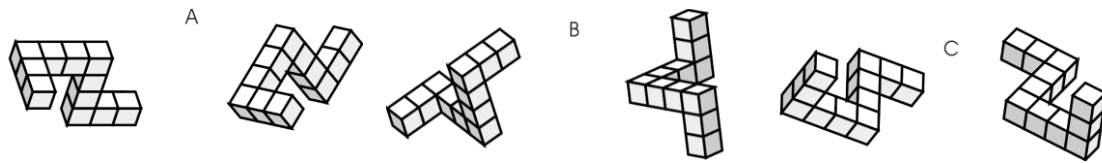


Figure 61 - Example of Mental rotation test exercise

Sub-task 1 is a mental rotation test (Shepard & Metzler, 1971) that has been transferred on a touch tablet for practical reasons. It tests the ability of spatial perception. This test consists in a series of exercises in which the subject has to identify similar shapes that have been rotated into space (cf. Figure 61).

- **Sub-task 2 & 5:** Traditional and Immersive object copy-sketching (ID, TD) 6 minutes

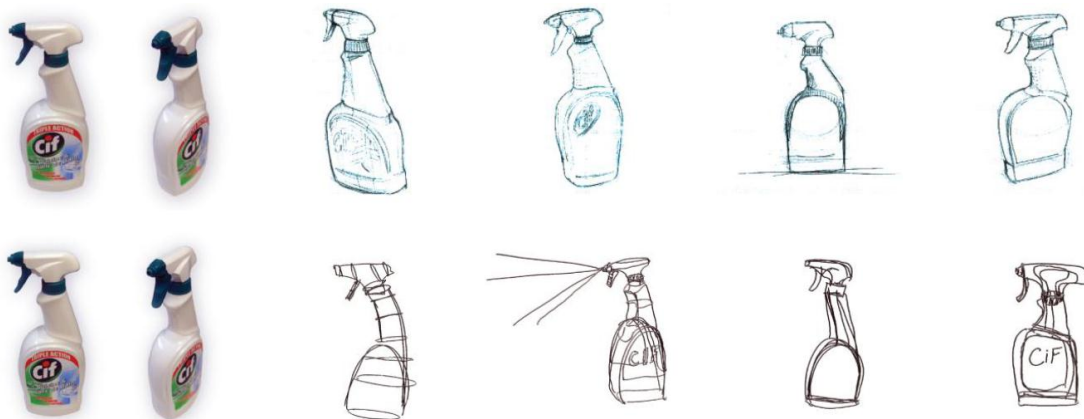


Figure 62 - Examples of traditional & Immersive copy-sketches

This study is completed in order to understand if the drawing expertise of a designer using traditional sketching techniques has an impact on his copying performance in immersive sketching. In these sub-tasks, the subject is asked to copy an existing object using traditional sketching tools and then with the immersive sketching tool (cf. Figure 62). The quality of their sketches is correlated with those of *Sub-task 5* in order to understand if traditional skills impact immersive skills. These sub-tasks are timed so that the user has 5 minutes to complete his sketching.

- **Sub-task 3:** Immersive sketching explanation (ID, TD, ND) 3 minutes



Figure 63 - Immersive sketching controller & features

This part of the experiment is dedicated to the explanation and demonstration of the controls and features enabled by the immersive system. The functions are the following: *3D Sketching*, *Erasing* and *Moving 3D sketch* and *Switching* from the immersive moodboard to the sketching canvas (cf. Figure 63).

- **Sub-task 4:** Free Sketch (ID, TD, ND) 10-15 minutes

At this point, the participant makes his first traces by using the immersive interface. He is asked to draw a three dimensional cube, then a sphere and a cone, using the depth of the canvas. Once these three shapes are completed, the designer is left free to sketch until he desires to move on to the next sub-task (5-10min).

4.3.3.4.1.2 EARLY DESIGN TASK – TASK1

- **Sub-task 6 or 6':** Immersive or traditional moodboards evaluation (ID, TD) 5 minutes

The participant is next asked to evaluate the moodboard by using a questionnaire based on the evaluation done in EXP1. (§.4.2.4.2) (cf. Figure 64) The participant completes the semantic differential test composed of 9 pairs of opposite terms, intended to measure the semantic profile of both moodboards (*immersive moodboard & traditional moodboard*), the Osgood scale to assess the valiancy and intensity of the emotional experience induced by the stimuli, and the set of semantic scales composed of 10 semantic and emotional terms which goal is to characterize the emotional experience of the stimulated user.

Tendance

• Décrivez la scène à l'aide des échelles proposées:

	3	2	1	0	1	2	3	
Sombre	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Lumineux
Triste	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Joyeux
Courbe	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Droit
Original	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Classique
Élégant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Grossier
Vivant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Mort
Chaleureux	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Froid
Agité	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Calme
Réconfortant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Démoralisant

? Exemple: Sur une ligne comportant les termes " Volumineuse | Etroite " si vous cochez le chiffre 2 se trouvant plus proche de volumineuse que d'étroite, vous préférez qualifier la scène de volumineuse plutôt que d'étroite.

• Notez votre ressenti émotionnel global face à la scène présentée:

	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
Some example subquestion	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

? Exemple: Cocher +2, nous indique que votre ressenti émotionnel global est relativement positif.

• Notez les émotions en fonction de votre ressenti face à la scène présentée

	Pas du tout							Très
Calme	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Humble	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Dédaigneux	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Inspiré	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Détendu	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Perplexe	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
A l'aise	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Confiant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Intéressé	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Respectueux	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

? Exemple: Sur une ligne comportant l'émotion " Confus ", cocher une case proche du label " Très " indique que la scène induit chez vous une forte confusion.

Figure 64 - Semantic emotional questionnaire

- **Sub-task 7 or 7':** Immersive or traditional early design task (ID, TD) 20 max minutes

The designer is now asked to answer a design brief by generating a concept. *Design an espresso making machine for Nespresso respecting the style that is given to you on the moodboard.*

The team equipped with traditional tools (TD) is provided a moodboard, a mechanical pencil, a rubber and an infinite set of ISO A3 paper. The team equipped with immersive tools (ID) has an immersive system on which is loaded an immersive moodboard, in addition to an immersive sketching application. Both groups are allowed to explore by sketches, however they must produce one final concept that will be judged. At the beginning of this sub-task, the designer is told to use as much time as he wants. He may end this design activity whenever he desires. However he is encouraged to finish after 15 minutes of sketching.

4.3.3.4.1.3 EXPERIENCE FEEDBACK EVALUATION TASK – TASK2

- **Sub-task 8:** AttrakDiff (ID, TD) 5 minutes

After the design task, the immersive designer is asked to fill a survey based on the AttrakDiff evaluation tool. (Hassenzahl 2006). This method uses semantic differential survey centered on the

pragmatic and hedonic quality of the user's experience to characterize attractiveness. Thus this analysis describes

- the usability in terms of how successful the designers are in achieving their goals during the design task (pragmatic quality),
 - how the system stimulates the participants towards *interest, novelty, interaction and engagement* in the design task (hedonic quality - stimulation),
 - how much the designers identify themselves with the immersive tools (hedonic quality - identification),
 - the overall value of the tool set (attractiveness).
- **Sub-task 9:** Semi-directed interview (ID, TD) 5-10 minutes

The semi directive interview is a survey during which the user is asked to comment his answers to the questions. The first sets of questions are composed of randomly ordered Likert scales so that the participant may describe his experience using seven axes. These factors were determined beforehand during pilot studies (cf. Table 5)

Factors	Descriptions
Externalization capacity	Extent to which it is easy to express what one has in mind.
Learning facility	Facility relating the speed and ease before one can handle the immersive design experience.
Spatial thinking capacity	Extent to which the immersive system helps the designer coordinates his thinking around spatial mental objects.
Creation facility	Extent to which the system assists the design in his design task.
Stroke fluidity	Extent to which the designer experience an adequately fluid stroke
Precision	Physical precision enabled by the system.
Refinement facility	Extent to which one is able to refine the drawn shape

Table 5 - Experience feedback scales

The designer is then invited to express a minimum of 4 features he likes and 4 he dislikes during the immersive design experience. He is then invited to describe the features he would like to experience or he feels as missing to the early immersive experience.

- **Sub-task 10:** Fatigue survey (ID, TD) 1 minute

Finally the designer is asked to evaluate his mental and physical fatigue and his global fatigue, using a semantic scale for each of these factors. The end to end length of this experiment is of 65 minutes, 30 of which are spent in sketching activity.

- **End:** End of in-laboratory experiment

The in-laboratory test ends on this sub-task. The design concept are compiled and transcribed

without re-interpretation so that their representation styles are indiscriminant.

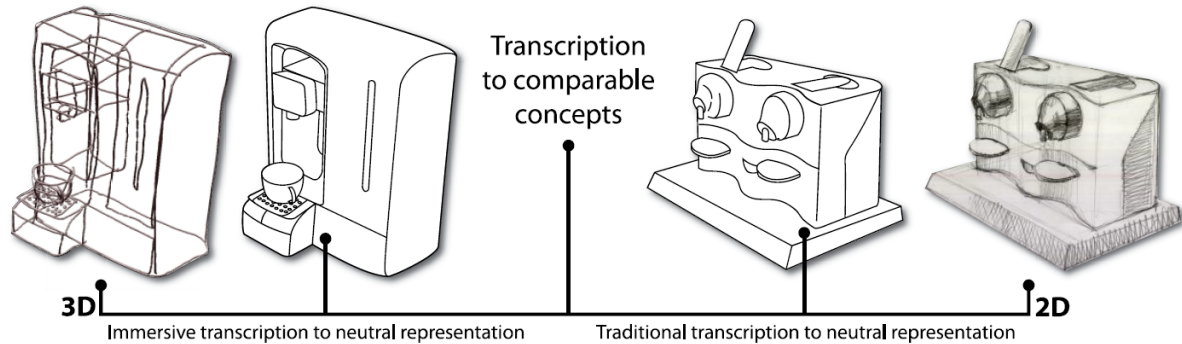


Figure 65 – Example of Transcription of design concepts into neutral style

This common representation style conceals the sketches source and guaranties that the shapes are evaluated with no regard to the process from which they originate. In order to ensure that the transcription does not suppress any concept related information, this transcription work is done rigorously and is validated by the original designer.

This sub-task marks the end of in-laboratory experiment. The upcoming sub-tasks are part of an online survey involving 10 end-users, 10 master designers and 5 art professors.

4.3.3.4.2 ONLINE EXPERIMENTAL PROCEDURE

The prior sections have presented the in-laboratory segment of the experimentation (cf. Figure 66). The purpose of this second segment of this experiment is to evaluate the sketches produced during the first segment. The concepts produced during the early design sub-tasks are evaluated by end-users and master designers. The copy-sketches drawn in sub-task 2 and 5 are evaluated by a panel of art professors. This part of the experiment occurs online and worldwide.

Impact of the Immersive Experience on Kansei During Early Design - 2013-ENAM-0027.

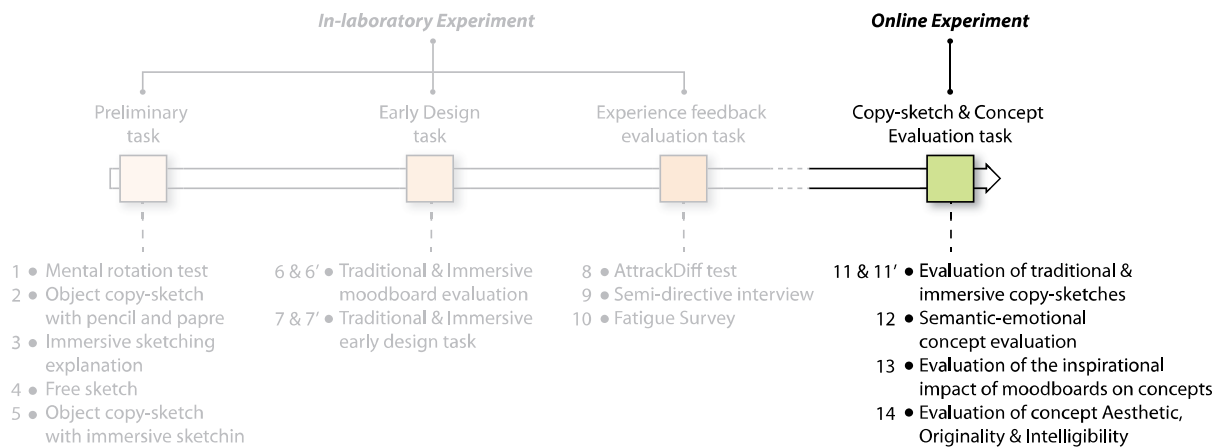


Figure 66 - Online task distribution

The next section details the sub tasks of the online segment of the experimentation.

- **Sub-task 11 & 11'**: Evaluation of the traditional or Immersive sketches of copied objects (AP)

This Sub-task is the evaluation of the traditional copy sketches completed during *Sub-task 2* and the immersive copy sketches from *Sub-task 5*. The art professors evaluating those sketches are asked to judge the traditional and immersive copy-sketching expertise, based on the representation techniques to copy a given model.

- **Sub-task 12**: Semantic-emotional concept evaluation (EU)

In this sub-task, the end-users are asked to evaluate the concepts using the same scales that have been used to evaluate the moodboards in *Sub-task 6 & 6*. We thus can generate a semantic and emotional profile of the designed concepts in the same way as we have generated the semantic and emotional profiles of the moodboards (§4.3.4.3.2) (cf. Figure 64).

- **Sub-task 13**: Evaluation of the inspirational impact of the moodboard on the concepts (MD)

This section of the questionnaire is intended to measure the extent to which the designers have inspired themselves of the moodboard they were given during the design task. The master designers are asked to process this evaluation on a scale from 0 to 100 for defining the proportion of inspiration drawn from the moodboard and found in the concept.

- **Sub-task 14**: Aesthetics, Originality and Intelligibility of concept evaluation (EU)

In this final sub-task, a group of end-user is to evaluate the concept onto three qualitative dimensions: the *aesthetics* quality of the concepts; their *originality* and their *intelligibility*.

- **End**: The experimental procedure ends on this sub-task.

4.3.3.5 PILOT STUDIES

This study raised difficulties due to the complexity of the procedure and revealed the necessity of a semi-automated experimentation. In addition to freeing the experimenter, this semi-automated process delivers the same audio information from a designer to another. By triggering experimental phases, timing and measuring tools management are all time-stamped by a central clock and a programmable logic controller.

The pilot studies also showed the importance of a frequently asked question audio data base. Especially in order to define the semantic terms used in the semantic and emotional questionnaires (cf. 3.1.2.1 procedure). This definition data base helps in keeping the experimentation objective.

The research experience generated by EXP 1 has also prompted some modification of EXP2. For instance, a modular interactive online survey has been designed. The pilot studies featuring industrial design students, engineering design students, and the review of advanced researchers and professors from the NPDIL have enabled:

- The calibration of the experiments complexity, length and speed of the experiment
- The selection of the nature, of the number of semantic terms and of the range of semantic scales in order to obtain discriminant semantic-emotional profiles
- The identification of the design brief used for the fictive design task (*Sub-task 7 & 7'*): the object to be designed, the brand for which it is designed and the moodboard from which to design.

The moodboard is selected in reference to the result of EXP1. "Cube" (cf. 4.2.4.1), as the moodboard is called, is the most physiological emotionally stimulating moodboard in immersive and *traditional condition*.

4.3.3.6 PROTOCOL ANALYSIS

Our study implies to perform operations on the data before being able to analyze it. These transformations are executed to enable the objective inter-personal and intra-personal comparison. These three operations are:

- Video coding of the observed early design activities.
- Application of statistical analysis
- Galvanic skin response data cleansing

These operations are detailed in the next three sub-sections.

This fictive design process is voluntarily minimalized to catalyze any phenomenon appearing during the early design activities in a more real content. For instance reducing the designers' tools to a pen and paper can seem radical. However this simplicity is necessary to underline any complex singularity which is happening during the design task. Another reduction is to provide a ready-made moodboard to the designer as if it were naturally a part of the brief, simulating a request from the style department. The interviews have shown that within the tested industrial designers, some of them are daily implied in the trend analysis whereas some do not formalize any inspirational material into moodboard.

4.3.3.6.1 VIDEO CODING SCHEME

In order to understand and compare the immersive design activity to its traditional version, we have developed a common code scheme. This code is linked to the functionalities available to the designers in both workspaces. A downgrading modification has been operated on the immersive sketching experience so that only features which are analogues to the traditional experience are activated. *Toggle moodboard/sketch workspace*, *sketch*, *erase* and *move sketch* are the four features available corresponding to four different commands (cf. procedure - Sub-task 3). *Layers management*, *color selection*, *independent layer manipulation*, *scaling* and *computer aided design model insertion* are deactivated in order to obtain comparable activities. In both immersive and *traditional conditions*, a camera is set so that the activity can be coded during post-experimental data analysis (cf. Figure 67). The activity is coded in 4 sub-categories:

- **Inspiration:** The inspirational time represents the period during which the designer looks at the (immersive) moodboard. As in the *immersive condition*, the designer is not able to draw and view the moodboard at the same time; a system has been implemented in the *traditional condition* so that the designer is forced to stop sketching while looking at the moodboard.
- **Observation:** The observation time is the time during which the designer is looking at his production and/or moving his (immersive) sketch.
- **Sketching:** The sketching time is the time recorded when the designer leaves a trace.
- **Deletion:** The deletion time is the time during which the designer is erasing the traces he has made.

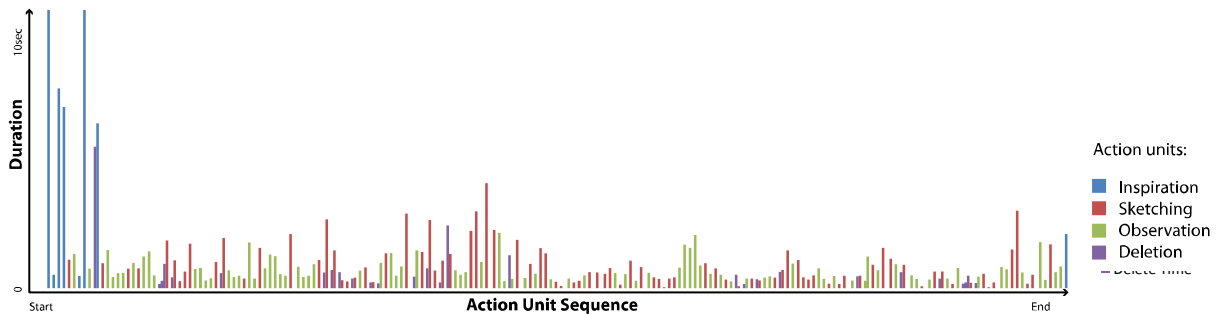


Figure 67 - a) Examples of coded early design activity

The coding and comparison of the activity of both groups makes it possible to know how the *immersive condition* and 3D tools modifies the designer's activity.

4.3.3.6.2 STATISTICAL ANALYSIS

In order to grasp the different aspects of the activity, we deploy series of statistical tools. The comparative method defined as the framework for the empirical study positions the *immersive* and *traditional conditions* as the differentiation criteria (independent variable). The dependent variables monitored during the design task are inter-subject's parameters like activity unit duration or galvanic skin peak count. In order to select the type of statistical study to apply in our analysis, we run 2 tests related to the normal distribution and the equality variance of the data. A Shapiro-Wilk test is deployed to test the normal distribution of the data and a Levene test is applied to test the equality of variance. A non-normally distributed data is analyzed with a Wilcoxon's test and a normally distributed with a Student's test.

4.3.3.6.3 GALVANIC SKIN RESPONSE COMPUTATION

In order to compare galvanic skin response from a person to another, the data is normalized within each participant's response using the min-max normalization method. The data is resampled at 50Hz and smoothed at an average value based on a 3 sample scope.

In order to calculate galvanic skin response peak frequency, the derivative signal is used to detect peaks greater than a sixth of the total signal variation. (Dawson, 2004)

4.3.4 RESULTS

In this section, based on the comparative protocols, we first intend to identify the impact of the designer's spatial immersive workspace on his inspirational and generational activity and the resulting concepts. Our second objective is to understand how emotions impact the creative process. We consequently apply our coding scheme and questionnaires analyses. The operated data are summarized in the following 3 sections:

- Study of the early design task (§4.3.4.1)
 - Impact of the spatial immersive workspace on time-use in early inspirational and generational phases. (§4.3.4.1.1)
 - Impact of the spatial immersive workspace on the emotional response during early design activity (§4.3.4.1.6)
- Study of the copy-sketches and concept evaluation task (§4.3.4.2)
 - Impact of the spatial immersive workspace on semantic and emotional relationship between industrial designer and end-user (§4.3.4.2.1)
 - Impact of the spatial immersive workspace on aesthetic, originality and intelligibility of the generated concepts (§4.3.4.2.2)
- Study of the experience feedback evaluation task (§4.3.4.3)
 - AttrakDiff survey: pragmatic, hedonic qualities and attractiveness (§4.3.4.3.1)
 - Adequateness of on the immersive early design experience to the industrial designer's needs (§4.3.4.3.2)
 - Assets and weaknesses of the immersive early design experience (§4.3.4.3.3)
 - Inspirational impact of the designer (§4.3.4.3.4)
 - Fatigue survey (§4.3.4.3.5)

Finally the results are synthesized to key results (§4.3.4.3.6) and discussed (§4.3.4.3.7)

4.3.4.1 STUDY OF THE EARLY DESIGN TASK

The following sections relate the results providing from the analysis of the *early design task*.

The following section presents the results of:

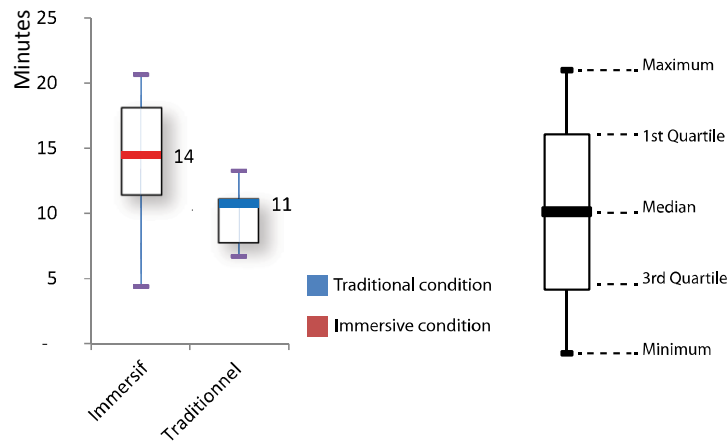
- The impact of the spatial immersive workspace on time-use in early inspirational and generational phases §.4.3.4.1.1
- The impact of the spatial immersive workspace on the emotional response during early design activity §.4.3.4.1.6

4.3.4.1.1 IMPACT OF THE SPATIAL IMMERSIVE WORKSPACE ON TIME-USE IN EARLY INSPIRATIONAL AND GENERATIONAL PHASES.

In this section we show how the immersive experience of early design is different from its traditional equivalent by focusing on time management. A video analysis of the *early design task* (Sub task 7 & 7') is executed by using the activity units (cf. 3.1.2.1): *inspiration, observation, sketching, and deletion*. The first section of this chapter focuses the total time used to complete the design task and the second section presents an analysis of the breakdown of the total design activity using the activity video coding method.

4.3.4.1.2 TRADITIONAL AND IMMERSIVE TOTAL EARLY DESIGN TIME COMPARISON.

A first indicator differentiating immersive activity from the traditional activity is the duration between the time they receive the brief and the time they complete their concept sketch (cf. Figure 68). The results are synthetized by box-whiskers showing the maximum and the minimum (horizontal purple dashes, respectively on top and at the bottom of the data), the first and the third quartiles (respectively the top and the bottom of the box). The median is depicted as a horizontal dash, blue for the traditional condition, and red for the immersive one. During the design task, the designers are free to manage their time. They are required to produce a final concept based on a brief and to end their design activity when they are satisfied with the result. They are encouraged to stop after twenty minutes have passed. The results show that the spatial immersive early design configuration has a significant effect on the designer's management of time.

Figure 68 - Impact of *immersive condition* total design time

The designers in *traditional condition* tend to use a time frame ranging from 7 to 13 minutes whereas the designers in *immersive condition* have a more distributed time ranging from 4 to 21 minutes. However, on average, the designers spend 3 minutes more in *immersive condition* with a total of 14 minutes of design for designers in *immersive condition* and 11 minutes for designers in *traditional condition*.

The statistical tests suggest a Student's test should be used to determine significance. A Student's shows that there is a statistical significant difference between *immersive* and *traditional conditions*, $p\text{-value} = 0.0217 \leq 0.05$. Thus *immersive condition* significantly increases the total time spent designing in order to obtain a self-satisfying concept.

Professional industrial designers tend to extend their early design activity when using the immersive workspace, yet quite exceptionally some designers in the *immersive condition* have executed their design task in less time than any of the designers in *traditional condition*.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow
Duration	Total early design task	Early design task	Sub-task 7 & 7'	↑ + 5 min

Table 6 - Synthesis of the impact of immersion on the total early design task duration

The next analysis examines the data deeply by subdividing the early design activity into activity units. This upcoming study gives precision to the analysis by detailing the observed design activity in *immersive* and designers in *traditional condition*. As for all the results, these are presented with the same type of box-whiskers and the same codes as before.

4.3.4.1.3 ACTIVITY CODING ANALYSIS

The following work relates the breakdown of the design activity and its statistical analysis (cf. Table 7 p.119). In this section, a study of the effect the immersive or *traditional condition* on the time spent during the different activity units is presented: *inspiration*; *observation*; *sketching* and *deletion*.

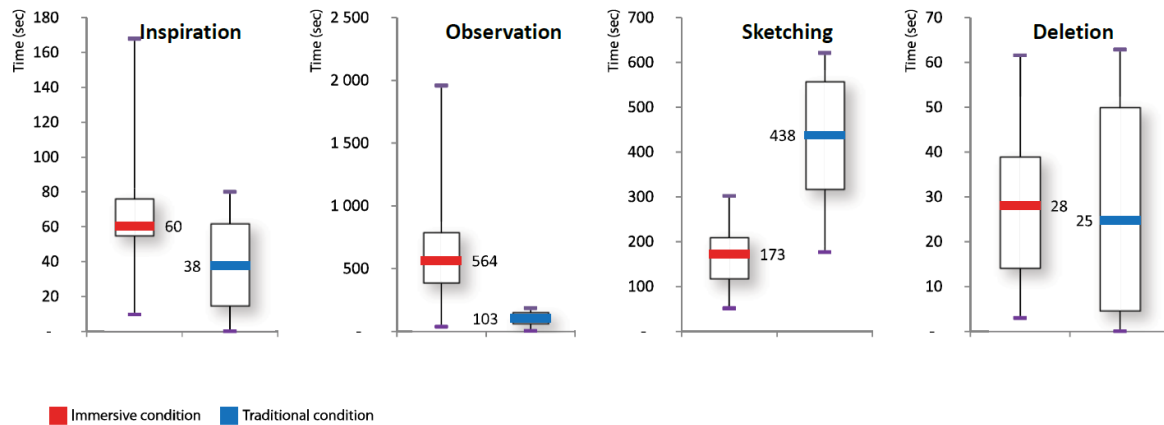


Figure 69 - Impact of *immersive condition* activity units duration

Figure 69 shows how the designers part their time. This figure is an outcome of the video and automatic coding of the activity. The results show the impact of the *immersive condition* on the time management in early design activity. We observe that the total time spent in *inspiration*, *observation*, and *sketching* vary largely from one condition to another.

An average time of 22 seconds more is spent using the immersive moodboards in comparison with traditional moodboards. The average time spent by the designer observing and manipulating his virtual sketch and its content is more than five times superior (x5) to the time spent *observing* and manipulating the two dimensional sketch. On average, the designers in *immersive condition* also spend two and a half times less time *sketching*. As for *deletion*, the average time during which the immersive designer deletes parts of his sketch is close to similar than that of the traditional designer. The dominant activity in immersive design is *observation* and sketch manipulation whereas in traditional activity *sketching* occupies most of the designers time.

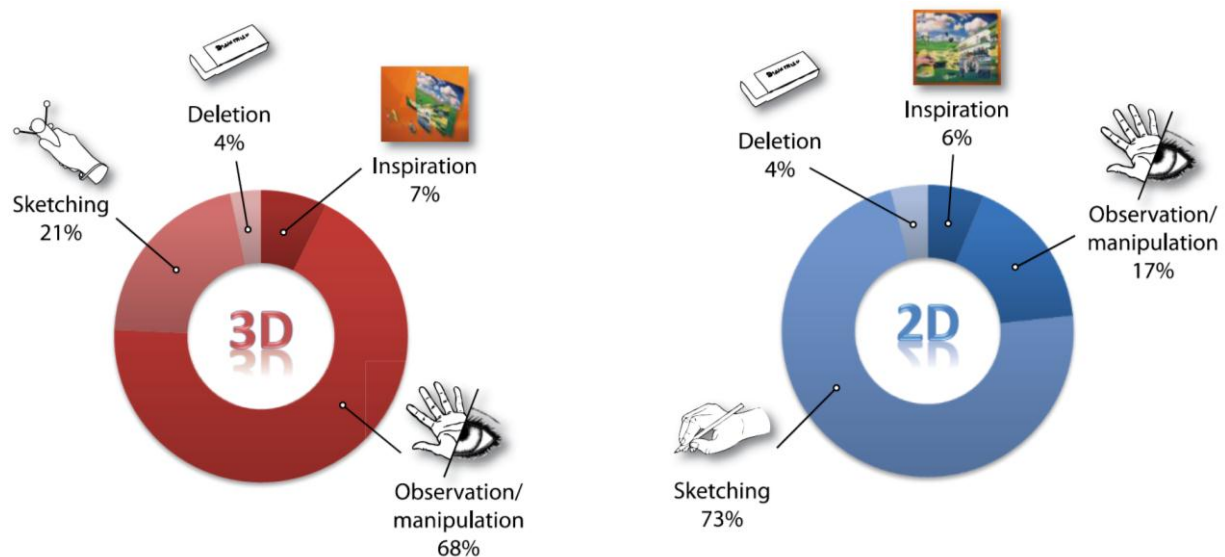


Figure 70 - Impact of *immersive condition* on activity unit duration percentage

By looking at the proportion rather than at the absolute time, the effect of the global task length difference is suppressed (cf. Figure 70). This normalized analysis reveals that the design team in *immersive condition* spend a fifth (~20%) of their time *sketching* their concept and more than half (~70%) of their time manipulating and observing their design. This is the diametrically opposite to what we observe when studying the team in *traditional condition*. The team in *traditional condition* who spend near to a fifth (~20%) of their time *manipulating and observing* and more than two third *sketching* (~70%).

The statistical tests suggest a Wilcoxon's test should be used to determine significance of the immersive condition on time spent in the *inspiration*, *observation* and *sketching* activity unit, however, a Student's test is more suited for the deletion activity unit.

The immersive condition is found to have a significant effect on the time spent in *inspiration*, *observation* and *sketching* activity unit but not on *deletion*. With respect to participants designing in *traditional condition*, participants designing in the *immersive condition* are thus found to have a significantly increased *inspiration* ($p=0.0433$) and *observation* ($p=0.0002$) time while decreasing their *sketching* ($p=0.0004$) time to complete the design task and obtain a satisfying concept. This analysis helps us precise the results observed (in 3.4.1.1) by identifying an increased inspiration and observation time and decreased sketching time induced by a spatial immersive workflow.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow			
				Inspiration	Observation	Sketching	Deletion
Duration	Activity Units	Early design task	Sub-task 7 & 7'	↓ /1.5 sec	↑ x5.5 sec	↓ /2.5 sec	↑ + 3 sec

Table 7 - Synthesis of the Impact of the immersion on duration of the activity units

4.3.4.1.4 DISCUSSION

These results can be explained by the fact that the entire population of participants is far more trained in traditional design than in immersive design. The proportional inversion between sketching and observation can be due to the lack of experience and tacit knowledge of the participants in immersive early design. The increase in observation and manipulation behavior noted in *immersive condition* could be the result of an exploratory comportment aimed to understand the experience while designing. We observe that the designers in *traditional condition* finish their design task in the same amount of time (6 min bandwidth) compared to the total duration of the all immersive process varies from (17 min bandwidth). This indicates that there is a consensus around the time spent to traditionally design a concept but the *immersive condition* tends to engage a more exploratory approach to the early design task. In addition, these results must be taken into account, knowing that virtual tasks and environments influence the time perception of a participant. “*Time flies when I'm drawing*” said one of the designers spontaneously after hearing the time she had spent in immersion. Thus the difference inherent to both conditions may have elapsed time compression or expansion effect. However, it is expressly indicated in the task brief that the designers are to manage their time and stop whenever they are satisfied with the resulting concept. Thus the different proportion noted in *observation* and *manipulation* in the two conditions can be the result of individual choices made in response to the opportunities given by both experiences. The enjoyment of the designer in each action unit is a factor that can have impact on time management.

4.3.4.1.5 KEY RESULTS RELATED TO THE IMPACT OF THE IMMERSIVE WORKSPACE ON TIME USE

We observe that changing the tools of the designers modifies how the designers engage into early design tasks.

The results suggest that the immersion of the designers in a three dimensional workspace reduce their *sketching* time and increase their *observation* and sketch *manipulation* time. This first analysis show that immersions induce time related alteration. The upcoming analyses assist in understanding the impact of a spatial immersive workflow on the early design activity and its outputted concept.

The next analysis aims to qualify the emotional activity during the early design task according to the condition in which it is executed.

4.3.4.1.6 IMPACT OF THE SPATIAL IMMERSIVE WORKSPACE ON THE EMOTIONAL RESPONSE DURING EARLY DESIGN ACTIVITY

In the present study, the issue explored is the emotional response of the designers during traditional and immersive early design task. Basing our observations on the activity coding approach, we have monitored the physiological emotional response of the designers and associated it to his ongoing design activity. The next three sections present:

1. The impact of the immersive condition on the **total number of GSC peaks** recorded during the **design activity from end to end**.
2. The impact of the immersive condition on the **number of GSC peaks** recorded during the different **activity units**.
3. The impact of the immersive condition on the **frequency of GSC peaks** during the different **activity units**.

4.3.4.1.7 PHYSIOLOGICAL EMOTIONAL ANALYSES OF THE TOTAL GALVANIC SKIN CONDUCTANCE PEAK COUNT DURING EARLY DESIGN TASK:

The following sections presents the data relative to the monitored physiological emotional response

during the immersive and traditional early design task and their comparison (cf. Table 8). This analysis is based on the study of galvanic skin conductance peak count and rates grounded on the theory that a high peak count and a high peak rate corresponds to a high emotional activity. We first focus on the overview of the emotional data with regard to the overall design task and then refine this analysis by segmenting the design activity using the activity units (*inspiration, observation, sketching and deletion*). The next figure is a presentation of the total galvanic skin conductance peak count in immersive and *traditional condition* during the design task. As seen before, it presents a comparison of medians, in addition to indicating maximum, minimum, first and third quartile values.

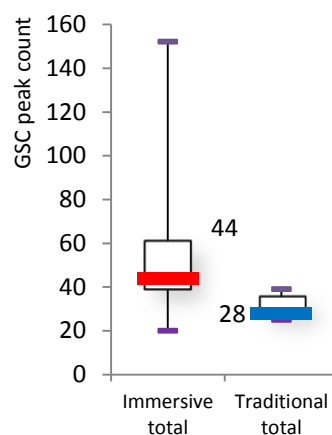


Figure 71 - Impact of the *immersive condition* on total galvanic skin conductance peak count during the design activity

A higher galvanic skin peak count average value (x1.6) is recorded on the designer group in the *immersive condition*. This result indicates that the designers in *immersive condition* have a higher emotional activity (richer in terms of peak) during their early design task.

Statistical trials suggest the use of a Wilcoxon's test. The test shows that there is a marginal significance of the immersive condition on the peak count, p-value = 0.051.

The data gathered implies that the designers tend to experience an increased number of galvanic skin peaks during immersive early design activity.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow
Galvanic Skin Conductance peak count	Total early design task	Early design task	Sub-task 7 & 7'	↑ x 1.5 peaks

Table 8 - Synthesis of the Impact of immersion on the galvanic skin conductance peak count during total early design task

4.3.4.1.8 PHYSIOLOGICAL EMOTIONAL ANALYSIS OF THE GALVANIC SKIN CONDUCTANCE PEAK COUNT OVER THE ACTIVITY UNITS OF THE EARLY DESIGN TASK

A closer look into the data gives a new outlook upon the emotional activity occurring during the early design task (cf. Table 9). The following figure (Figure 71) show the peak count per activity unit (cf. Figure 72). It is essential to keep in mind that the designers decide when to end their early design task thus resulting into design tasks lasting from 4 to 21 minutes.

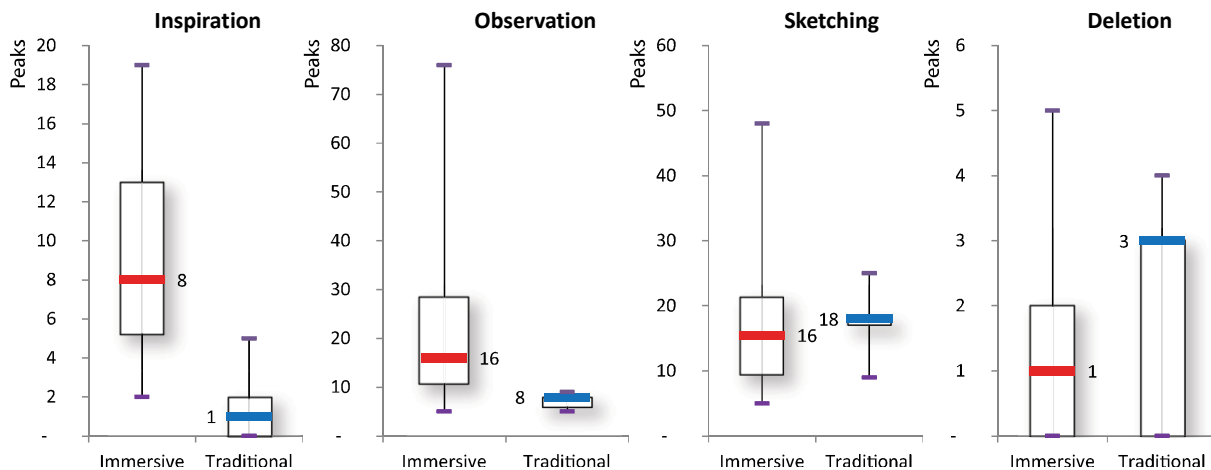


Figure 72 - Impact of the *immersive condition* on galvanic skin conductance peak count during activity units

On average, the designers in *immersive condition* experience eight times more peaks during inspirational activity (x8) and twice as much peak during observation (x2) as the traditional designer do. However we can see that on average the designers in *traditional condition* experience slightly more peaks in sketching (+2) and that deletion (x3) induces three times more peak than in designers in *immersive condition*.

Statistical trials suggest that a Wilcoxon's test for *observation*, *sketching* and *deletion* but a Student's test for *deletion*. The following table (cf. Table 9) shows the significance of the impact of the *immersive condition* on number of peaks during *inspiration* *observation* *sketching* and *deletion*. The statistical tests show that there is a statistical significant difference between *immersive conditions* *inspiration* and *observation* and *traditional conditions* *inspiration* and *observation*. (Inspiration, $p=0.0059$)(Observation, $p=0.0165$). However the differences between galvanic skin conductance peak count measured in *immersive* *sketching* and *deletion* are not significant. With respect to participants designing in the *traditional condition*, participants designing in the *immersive condition* are thus found to show a significantly increased emotional activity during *inspiration* and *observation* time.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow			
				Inspiration	Observation	Sketching	Deletion
Galvanic Skin Conductance peak count	Activity Units	Early design task	Sub-task 7 & 7'	↑ x 8 peaks	↑ x 2 peaks	↓ -2 peaks	↓ -2 peaks

Table 9 – Synthesis of the impact of immersion on the galvanic skin peak count during the activity units

The results presented in the prior analyses are to be put in perspective with the results found in §3.4.1. In the *immersive condition* and with respect to the *traditional condition*, the time used to design a concept and the galvanic skin peaks are increased. This raise: Is the galvanic skin peak count high because of an extended duration of the early design task or does the designer increases his immersive task duration because of a high emotional state? Evidence has been collected in EXP 1 and 2 showing that the immersive experience is emotionally engaging. However, the designers are novice in the use of the immersive device. The next analysis brings answers to this question by examining the ration of galvanic skin peak on duration of the design task.

4.3.4.1.9 ANALYSIS OF THE GALVANIC SKIN CONDUCTANCE PEAK FREQUENCIES DURING THE EARLY DESIGN TASK:

The preceding analysis characterizes the effect of the *immersive condition* on the designing time and on the emotional peaks generated (cf. Table 10). However to truly understand how the immersive tools can transform the designers activity in its emotional dimension, it is important to study the Galvanic Skin Conductance Peak Frequency (GSCPF) with regard to its activity unit (cf. Figure 73). In the following paragraph the emotional peak frequency of occurrence is to be assumed as the ratio of the total number of peak detected during an activity unit to the total time spent in this activity unit per participant.

$$GSCPF = \left(\frac{\text{total peak count}}{\text{total time}} \right) \text{ for each participants during each activity unit}$$

In this analysis, the GSCPF is the most crucial factor when observing the potential of a tool to induce a transformation in the emotional activity experienced during an early design task.

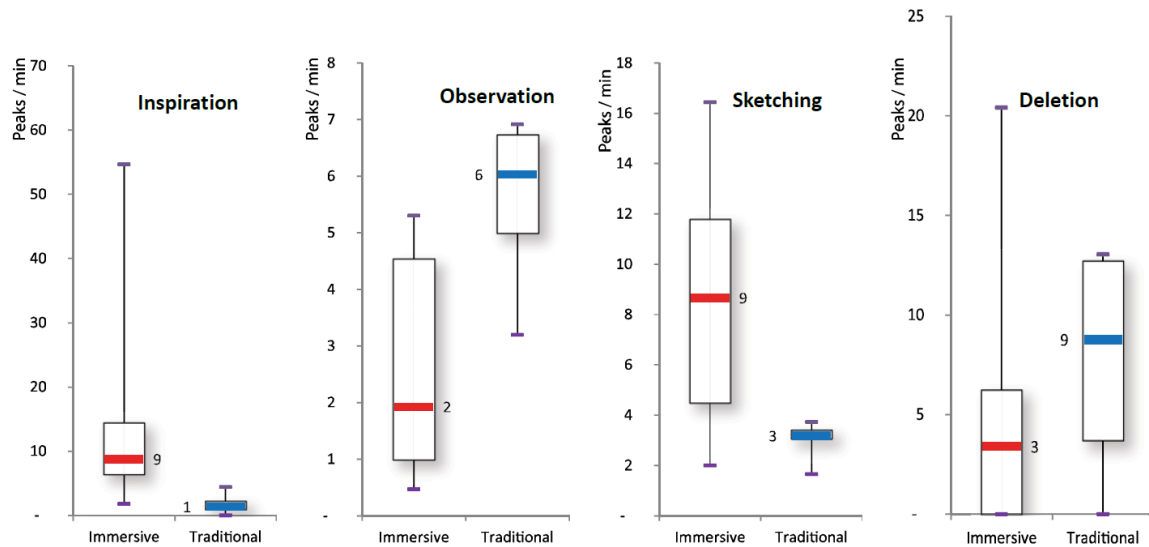


Figure 73 - Galvanic skin conductance peak frequency per activity unit

With respect to the designers in *traditional condition* and on average, we observe that the designers in *immersive condition* experience an GSCPF nine times higher when in inspiration(x9) activity and three times higher in sketching(x3) activity. However the designers in *immersive condition* experience a GSCPF three times lower in observation(/3) activity and seven times lower in deletion(/3) activity.

To test if the *immersive condition* has a significant impact on the GSCPF experienced by the designers, we use the statistic tools listed here above (cf. 3.3.7). Statistical trials suggest that a Wilcoxon's test must be used for the *inspiration*, *sketching* and *deletion* units. However, *observation* activity unit must be analyzed with a Student's test. We find that the condition has a significant effect on the GSPF during the *inspiration*, *observation* and *sketching* activity unit but not during *deletion*.

The immersive condition increases the frequency of galvanic peaks during *sketching* and *inspiration* but decreases the frequency during *observation*

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow			
				Inspiration	Observation	Sketching	Deletion
Galvanic Skin Conductance peak frequency	Activity Units	Early design task	Sub-task 7 & 7'	↑ x 6 peaks.min ⁻¹	↓ /3 peaks.min ⁻¹	↑ x 3 peaks.min ⁻¹	↓ /3 peaks.min ⁻¹

Table 10 - Synthesis of the Impact of immersion on the galvanic skin conductance peak frequency during the activity units

4.3.4.1.10 KEY RESULTS RELATED TO THE IMPACT OF THE IMMERSIVE WORKSPACE ON THE EMOTIONAL ACTIVITY DURING EARLY DESIGN

Our findings suggest that the immersive workflow significantly modifies the emotional early design activity. The galvanic skin conductance peak frequency is a time wise indicator of how emotionally impactful each activity unit is. This indicator is the calculated ratio between the activity unit duration and the galvanic skin conductance peak count. This ratio normalizes physiological emotional data on duration of each activity units. Thus this measure eliminates the effect of time extending processes such as learning. In view of the emotional physiological measures and with regard to designing in a traditional way with a pen, a paper and a moodboard, the immersive workflow increases the emotional value of the *inspiration and sketching* activity whereas it diminishes the emotional response of a designer *observing* his ongoing production. These results objectively validate the second hypothesis and demonstrate that a spatial immersive workflow modifies the emotional early design activity. They show that the immersive tools augment the early design activity concerning specific activity units such as inspiration and sketching. The immersion resulting in an increased emotional activity is a positive augmentation of the design process for:

- It enables a higher engagement of the designer in his task.
- It augments the designer's deep involvement in inspirational trend.
- It increases the coverage of the emotional features of the sketch in industrial design.
- It enhances the emotional component of the early design activity thus modifies the decision making process inherent to industrial design.

4.3.4.1.11 DISCUSSION

To embed emotions in a product is only possible if the designer is capable of identifying himself to the end-user through his tools. To understand and anticipate the emotion induced by a concept on a future end-user, the designer needs to be able to feel, assess and imagine the emotional impact of his concept through his tool and being. The evidence of an increased emotional activity in sketching and inspirational activity suggest an enjoyable experience. In that way, immersive moodboard and immersive sketching subjects the designer to a better experience induced by a moodboard or a sketch. The following result help in interpreting the previous results. The next study investigates the relationship between the designer and the end-user through the design product. The deeper investigation brings a new light on the results listed in the preceding analysis.

4.3.4.2 STUDY OF THE COPY-SKETCH AND CONCEPT EVALUATION TASK

The following sections relate the results providing from the analysis of the *copy-sketch and concept evaluation task* (cf. 4.3.3.4.1.1).

The following sections present conclusions on:

- Impact of the spatial immersive workspace on Semantic and emotional relationship between industrial designer and end-user §.4.3.4.2.1
- Impact of the spatial immersive workspace on Aesthetic, Originality and Intelligibility §.4.3.4.2.2

4.3.4.2.1 IMPACT OF THE SPATIAL IMMERSIVE WORKSPACE ON SEMANTIC AND EMOTIONAL RELATIONSHIP BETWEEN INDUSTRIAL DESIGNER AND END-USER

This analysis is based on the comparison between the semantic and emotional profile of the designer's inspirational material and of the semantic and emotional profiles of the design concepts perceived by the end-users (cf. Table 11). This section provides a comparison of data collected from traditional and *immersive moodboard semantic and emotional evaluation*, with the data collected during the *semantic and emotional concept evaluation* (sub-task 6 & 6' and sub-task 12). This analysis exposes the semantic *and* emotional proximity between the moodboard from which the designer inspires himself, and the design concepts perceived by the end-user. Furthermore, we study the immersive workflow on the semantic *and* emotional link between the inspiration and generation phases. The following figures define and illustrate the concept of semantic *and* emotional proximity (cf. Figure 74).

$$Proximity = \sum |(Moodboard \text{ term score} - Concept \text{ term score})|$$



Figure 74 – Examples of moodboard and concept emotional profile comparison

To compute the semantic *and* emotional proximity, we have subtracted the semantic *and* emotional profile of the moodboard as perceived by the groups of designers to the semantic *and* emotional profile of the concept perceived by potential end-users. The prior figure illustrates how the emotional proximity is determined (cf. Figure 74). Thus the closer the concepts are from the zero score the closer their profile is to the moodboard used to design this concept. The next figure shows the semantic *and* emotional proximity between the moodboard and the concept sketches and displays the workflow from which the concept originate (cf. Figure 75).

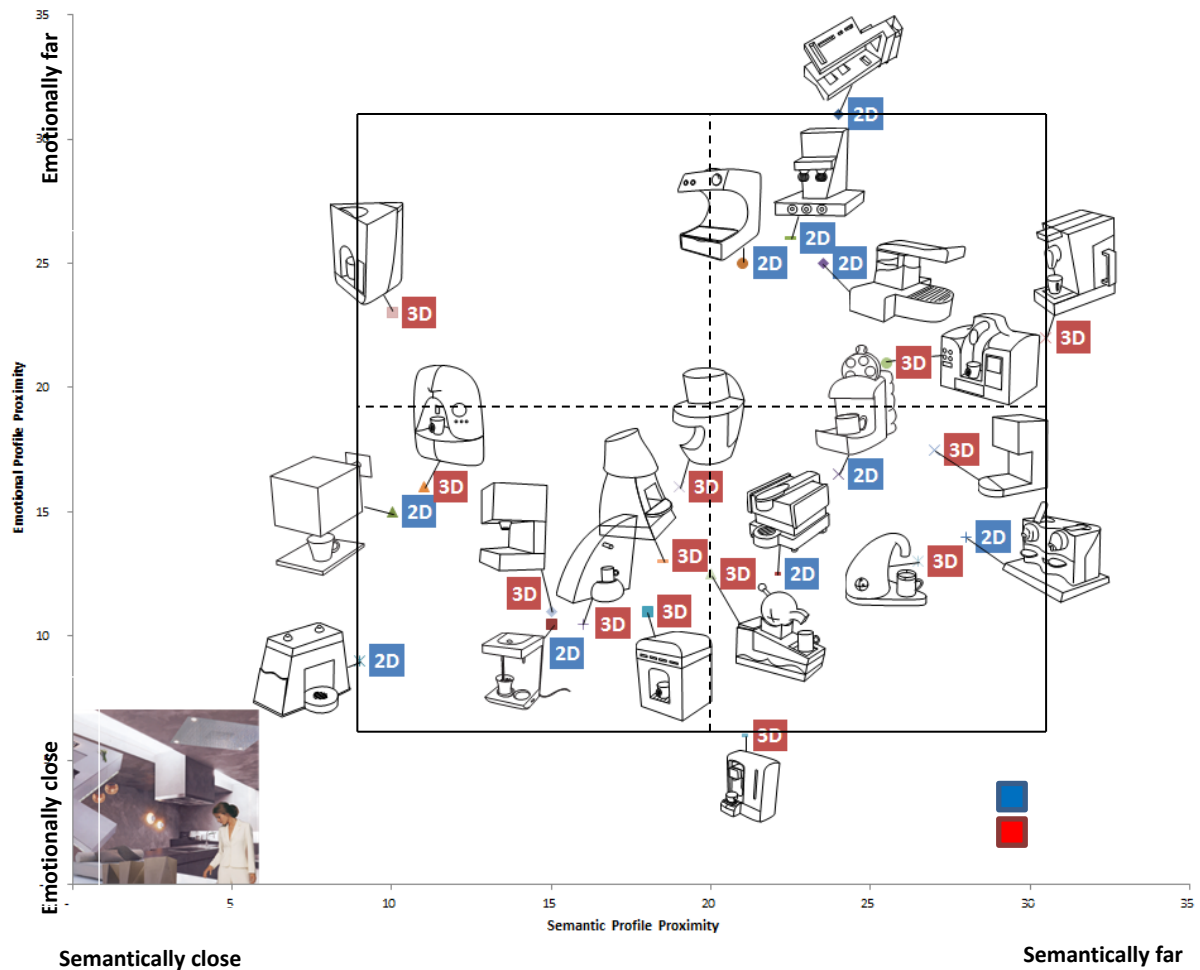


Figure 75 – Semantic and emotional proximity between the moodboard and the concepts with regard to immersive or traditional condition

The results show that the 3 concepts which match the most to the semantic - emotional profile of the moodboard are designed using traditional tools. However the concepts that are the farther from the profile are also designed in traditional condition. Substantially, 78% of the concepts designed in *immersive condition* are assessed as emotionally close to the moodboards. 18% less of the traditionally designed concept make it under this threshold. 54% of the concepts designed in *immersive condition* are semantically close for only 30% of the traditional concepts. Finally 16% of the concepts generated in *immersive condition* are semantically and emotionally closer with respect to the concept generated in *traditional condition*.

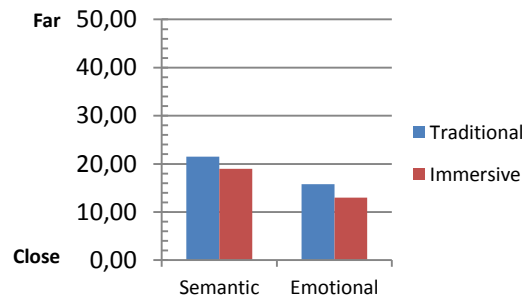


Figure 76 – Average semantic and emotional proximity comparison regarding traditional and immersive design workflow

The results of this analysis show that the average semantic and emotional profiles of the concept generated in immersive condition are closer to the semantic emotional profiles of the moodboard from which they are sketched. This indicates that the immersive workflow better assists the designer in communicating his intention to the end-user through his early design process (cf. Figure 76). This analysis suggests that the early immersive design does not only modify the activity of the designer but also impacts the relationship between the end-user and the design product. The spatial immersive confrontation between the designer, the inspirational trend and the sketch modifies the extent to which the designer addresses his intention to the end-user through the semantic and emotional component of the design concept. In this manner these result validate the second hypothesis and show that the immersive early design workflow modifies the concept semantic and emotional profile. This analysis suggests that the immersive early design process facilitates the transfer of semantic - emotional adequate attributes from the designer to the end-user. Thus it helps the designer in expressing the correct values to identified socio-economic group.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow
Semantic Proximity	Concepts	Early design task & Online concept evaluation	Sub-task 6 & 6', Sub-task 12	Concept semantic-emotionally closer to Moodboard

Table 11 - Synthesis of the impact of immersion on the semantic-emotional proximity between moodboard and concepts

4.3.4.2.2 IMPACT OF THE SPATIAL IMMERSIVE WORKSPACE ON AESTHETIC, ORIGINALITY AND INTELLIGIBILITY OF THE GENERATED CONCEPTS

This part of the study is centered on the end-user. The data analyzed here are provided by the evaluation of the concept produced during the *early design task* (sub-task 7 & 7'). They are evaluated by potential users on the *Aesthetic, Originality and Intelligibility* dimension (sub-task 14). To compare

the performance of a designer in immersive or traditional condition, a panel of end-users grades the concepts resulting from the 2 conditions (cf. Table 12). The *Aesthetic, Originality and Intelligibility* factors represent value from the end-users point of view. The immersive device has proven itself emotionally engaging and pleasurable for the industrial designer. This study observes the performance of the designer when using an early immersive device with regard to the traditional methods. The three identified criteria (*aesthetic, originality and intelligibility*) relate respectfully to the *pleasure, innovation and functionality* feeling induced by the shape feature of the concepts. *Pleasure, innovation and functionality* are major components of product design. The next figure shows the distribution of the concepts with regard to the three criteria. Figure 77 shows examples of the best concepts

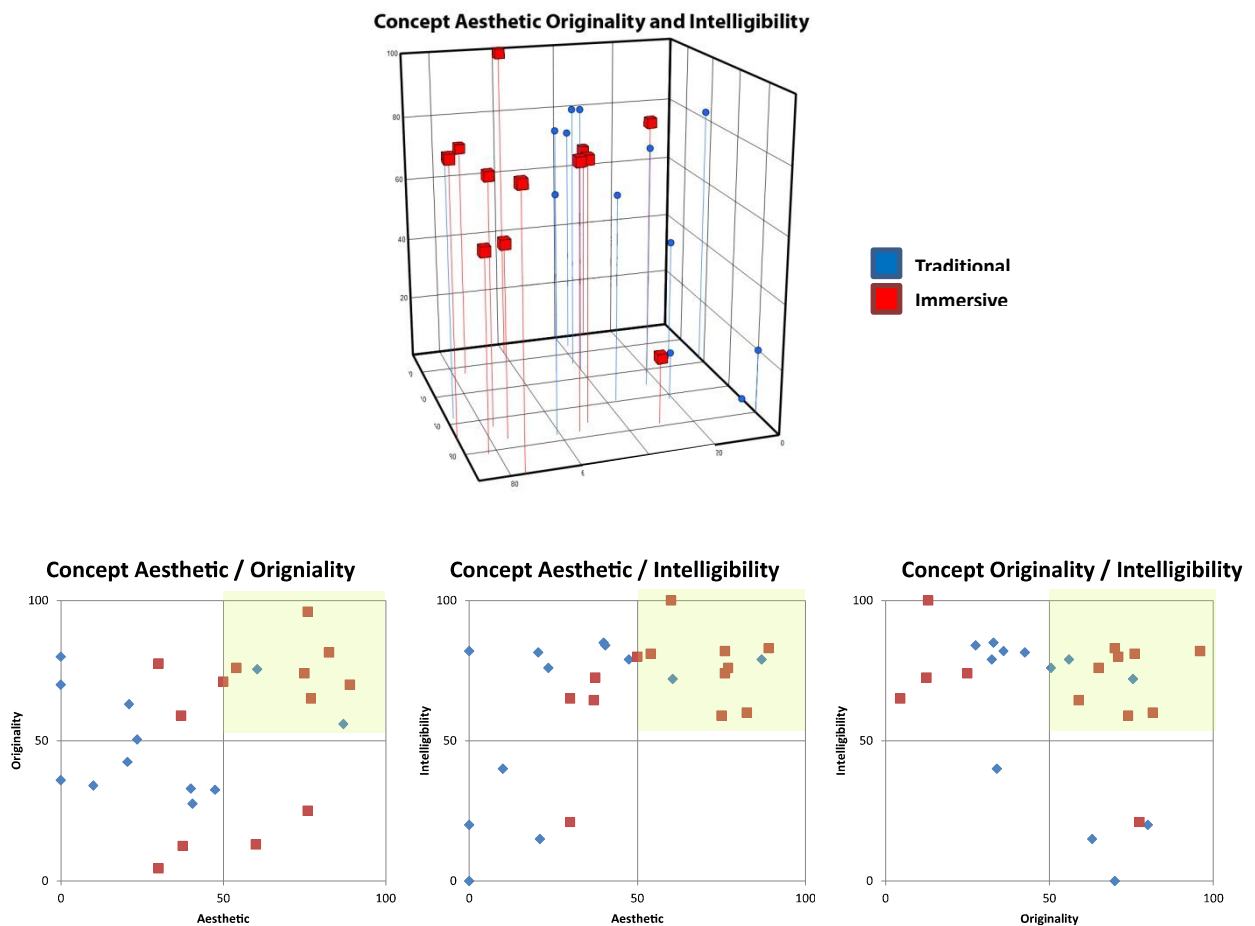


Figure 77 – Aesthetic, originality and intelligibility concept mapping

Data suggests that the *aesthetic and originality* component of the concepts are increased by the immersive condition. However, we do not observe a noteworthy difference between the *intelligibility* scores obtained by a traditional or immersive workflow. The mapping presented above indicates that 54% of the concepts generated in *immersive condition* obtain high *aesthetic, originality and*

intelligibility score (>50pts) whereas only 15% of the concepts generated in a traditional way obtain an equivalent score.

The results show that the immersive early design workflow significantly increases *aesthetics* and the *originality* of the concepts (cf. Figure 78). However *intelligibility* is not impacted by the used immersive or traditional condition.

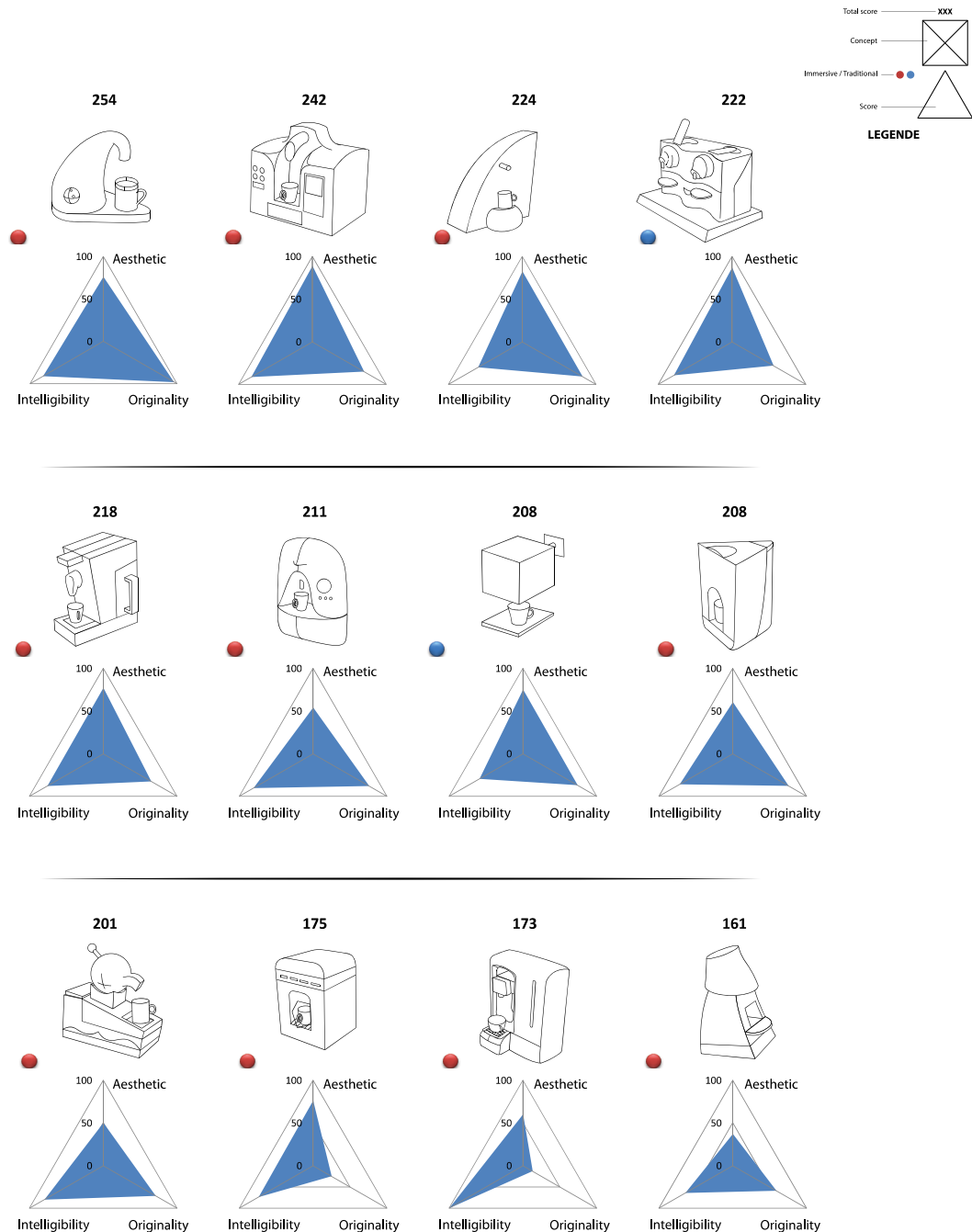


Figure 78 – First 12 concepts of the 24 with regard to Aesthetic, Originality and Intelligibility

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow		
				Aesthetic	Originality	Intelligibility
Aesthetic, Originality, Intelligibility	Concepts	Early design task & Online concept evaluation	Sub-task 7 & 7' & Sub-task 14	↑ Aesthetic	↑ Originality	Similar Intelligibility

Table 12 - Synthesis of the impact of immersion on the concepts aesthetic, originality and Intelligibility

4.3.4.3 STUDY OF THE EXPERIENCE FEEDBACK EVALUATION TASK

In order to develop a pleasurable experience, we have undertaken to objectively evaluate the match between the immersive workflow and the effective needs of the professional designer (cf. 4.3.3.4.1.3). This analysis is designed to measure how attractive the immersive workflow is to the professional designers. It is based on data collected from the designers after their completion of the design task. This analysis is grounded on four tests:

- an Attrakdiff™ survey § 4.3.4.3.1
- an experience survey § 4.3.4.3.2
- an open feedback on assets/weaknesses and a brainstorming on desirable features. § 4.3.4.3.3
- Inspirational impact of inspirational material § 4.3.4.3.4
- Fatigue survey § 4.3.4.3.5

These analyses aim to assess the present system and to detect opportunities for future developments and innovative concepts based on the industrial designer needs. The following results must however been acknowledged assuming the fact that the designers have only used the early design system for 30 minutes.

4.3.4.3.1 ATTRAKDIFF SURVEY: PRAGMATIC, HEDONIC QUALITIES AND ATTRACTIVENESS

The AttrakDiff test is a semantic differential based survey composed of four groups of calibrated opposed semantic terms: *Pragmatic qualities*; *Hedonic qualities of identification*; *Hedonic qualities of stimulation* and *Attractiveness* (cf. Table 14 p.134). The analyzed data arises from the *Attrakdiff test* sub-task (Sub-task 8). This test is part of the experience feedback task. It is designed to collect feedback from the designers who have used the immersive early design workflow. The next figure (cf. Figure 79) displays the results of this test following the four groups of semantic differential surveys:

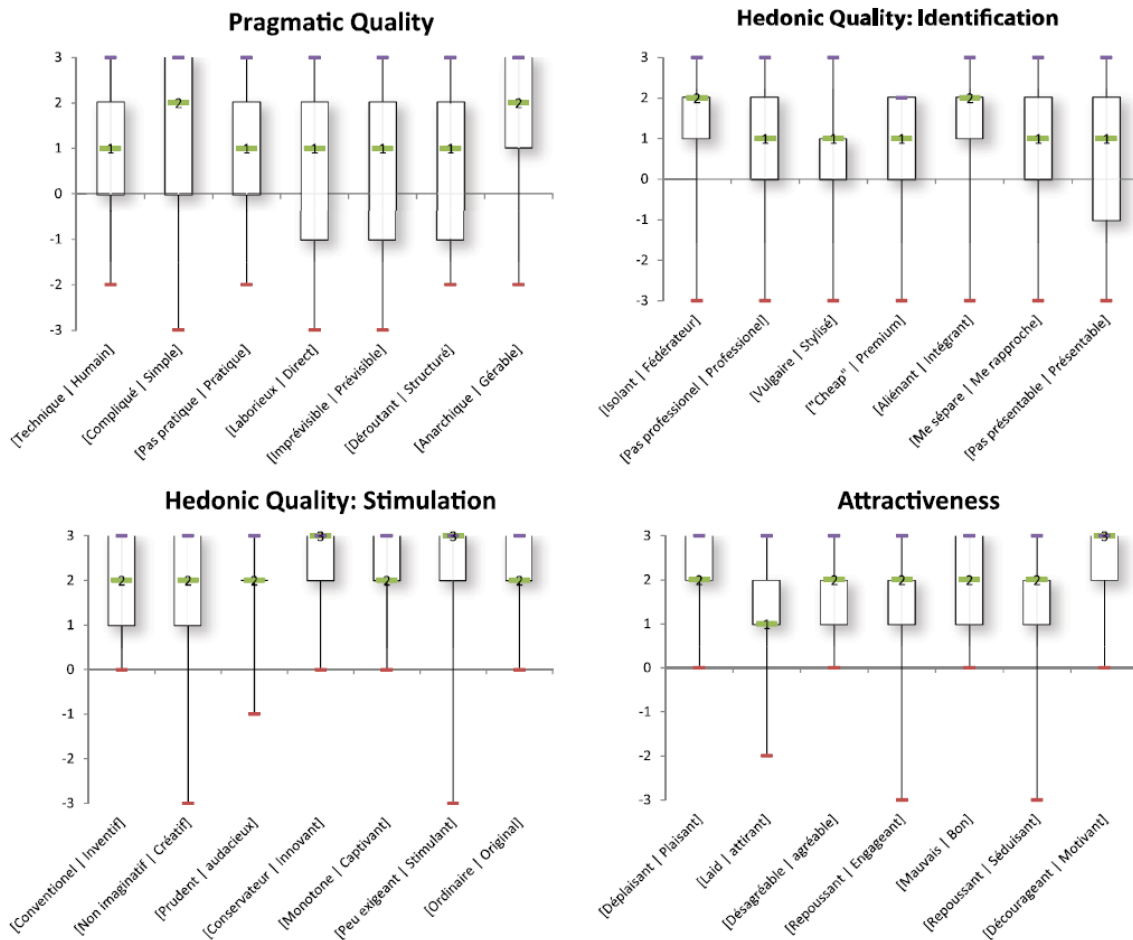


Figure 79 - AttrakDiff scores

The results are synthesized by box-whiskers showing the maximum (horizontal purple dash) and the minimum (horizontal red dash), the first and the third quartiles (respectively the top and the bottom of the box). The median is depicted as a horizontal green dash. As the data shows, the majority of the designers approve our *immersive* system. A +2 point threshold on the average values shows the system is:

Semantic Group	Feedback
Pragmatic Quality	Simple and manageable
Hedonic Quality - Identification	Connecting and integrating
Hedonic Quality - Stimulation	Inventive, Creative, Bold, Innovative, Captivating, Challenging, Original
Attractiveness	Pleasant, Agreeable, Engaging, Good, Appealing, Motivating

Table 13- AttrakDiff result summary

The experience scores the highest on the hedonic quality stimulation semantic groups and the pragmatic quality withholds the lowest scores, even though the scores are all positive. The collected results displayed in Figure 79 are presented under a different angle in Figure 80. This representation

shows the available improvement margin towards which the next version of the experience must tend.

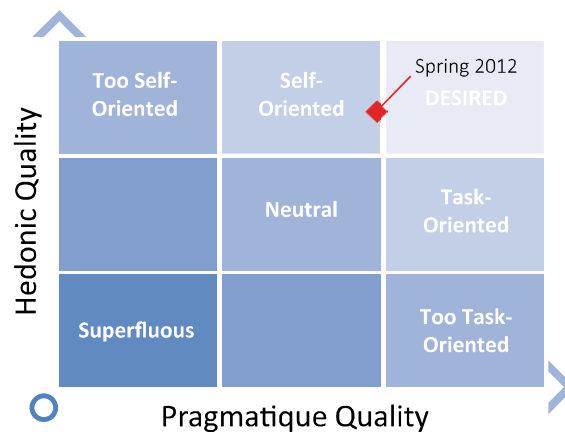


Figure 80 - Hedonic and Pragmatic Qualities: Attractiveness of the immersive early design experience

Figure 80 shows an indication that there is scope for further improvement of the experience. This unbalanced equilibrium between pragmatic qualities and hedonic qualities render the system self-oriented. This expresses the fact that the designer find they could execute their task in a more pragmatic fashion. The pleasurable and emotional aspects of the designed experience are however substantial. These measures are echoed and detailed by the following results.

Object of measure	Subject of measures	Task(s)	Sub-task(s)	Feedbacks on the Immersive early design experience			
				Pragmatic Quality	Hedonic Quality: Identification	Hedonic Quality: Stimulation	Attractiveness
Pragmatic Quality, Hedonic Quality & Attractiveness	Immersive early design experience	Early design task & Feedbacks	Sub-task 7 & 7' & Sub-task 8	Simple and manageable	Connecting and integrating	Inventive, Creative, Innovative, Captivating, Challenging, Original	Pleasant, Agreeable, Engaging, Good, Appealing, Motivating

Table 14 - Synthesis of the Attrakdiff survey arranger le tableau

4.3.4.3.2 ADEQUATENESS OF ON THE IMMERSIVE EARLY DESIGN EXPERIENCE TO THE INDUSTRIAL DESIGNER'S NEEDS

The next analysis is based on the *semi-directed analysis* sub-task (Sub-task 9). This test is a composed of a semantic scale survey composed of seven factors (cf. Figure 81). It is intended evaluate how the immersive early design experience fulfill the designers verbalized needs (cf. Table 15).

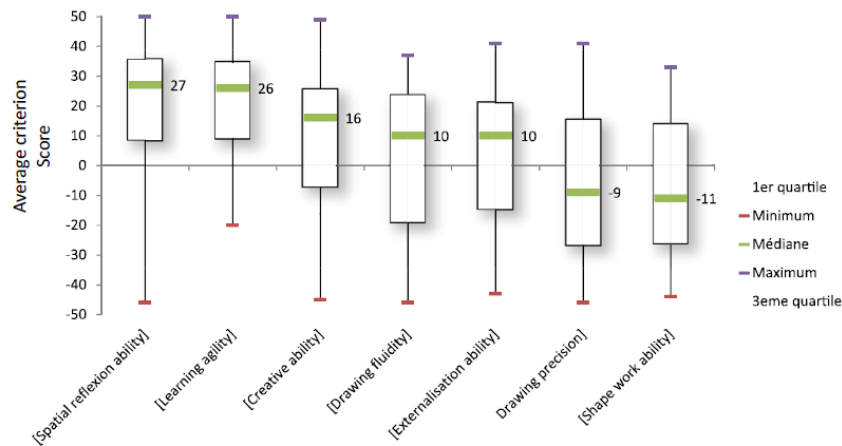


Figure 81 – Immersive early design experience

The data indicate that the proposed early design immersive experience empowers the designer with a good ability to think and resolve spatial problems. The participants have also assessed the extent to which learning how to use the system is easy as an asset to our device. The creative ability, drawing fluidity and externalization ability also collects a positive average score even though the scores are much more dispersed. However, the drawing precision as well as the ability to refine shapes is yet to be upgraded.

This analysis shows us that spatial immersive workflow provides advantages regarding spatial problem solving and fulfills the need for creative divergence specific to the generative early design activity. The results of this survey also suggest that the interactivity of the device has been well balanced regarding the learning agility of the users and their desire for a responsive device. There is an overall positive feedback supporting the idea that immersive design tools are suitable to think, diverge and create.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Feedbacks on the Immersive early design experience	
Feedback	Immersive early design experience	Early design task & Feedback	Sub-task 7 & 7' & Sub-task 9	Positive feedback	Negative feedback
				Spatial thinking, Learning ability, Creative ability, drawing fluidity, externalization ability	Drawing precision, Shape work ability

Table 15 - Synthesis of the feedback on the immersive early design experience

4.3.4.3.3 ASSETS AND WEAKNESSES OF THE IMMERSIVE EARLY DESIGN EXPERIENCE

The third part of this analysis consists in data collected from two exercises also completed during the *semi-directed analysis* sub-task (Sub-task 9), (cf. Table 16 p.138). The first is an experience feedback

during which the designers are asked to brainstorm and provide three assets and three flaws of the immersive early design experience. The next figure (cf. Figure 82) relates the number of designers addressing the same concept as an asset during this brainstorming:

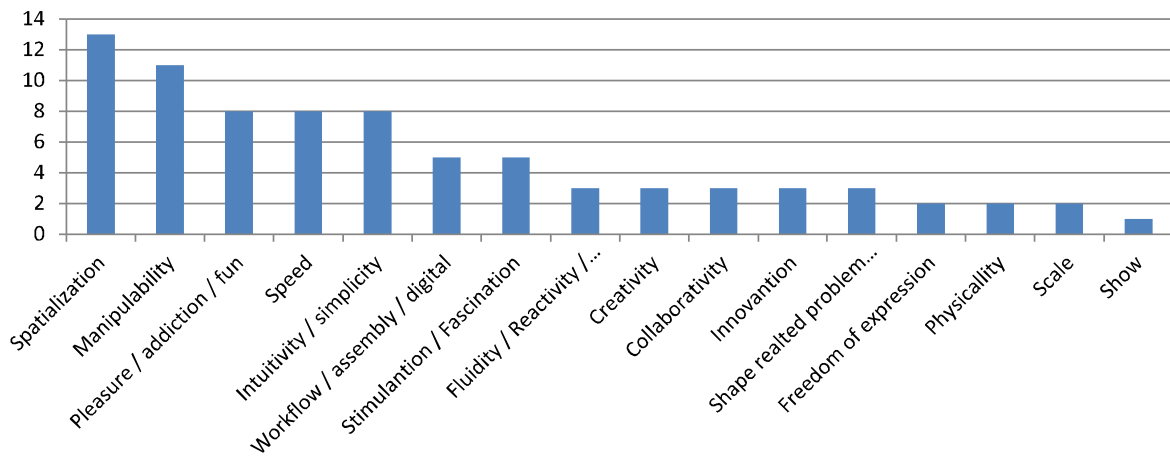


Figure 82 - Feedback on the assets of the immersive early design experience

The preferred assets of the immersive early design experience are *immersive spatialization*, *manipulability*. Participants have also related terms from the semantic fields of *pleasure*, *speed* and *ease of use* as a dominant asset of the experience. The next figure (cf.

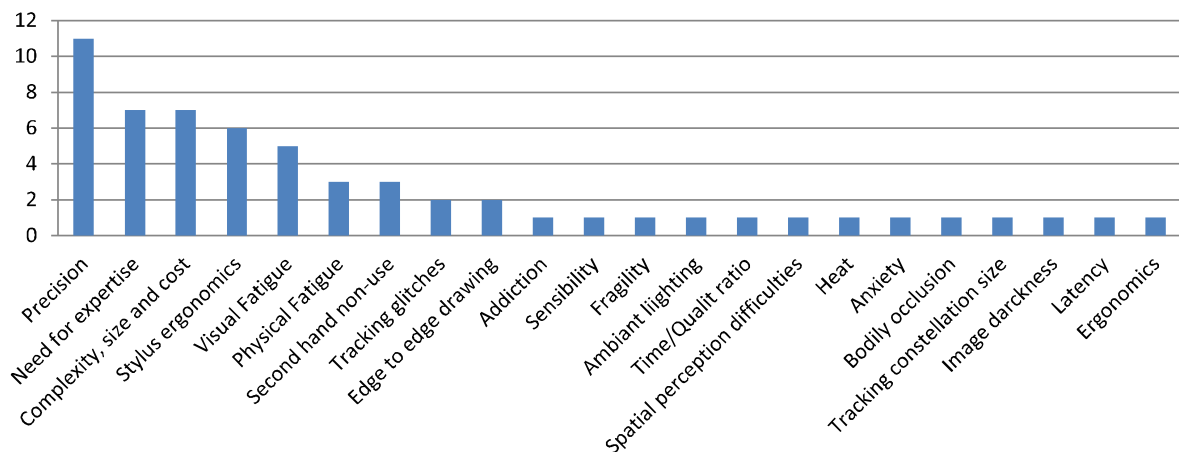


Figure 83) relates the number of designers addressing a concept as a weakness to the design experience:

Impact of the Immersive Experience on Kansei During Early Design - 2013-ENAM-0027.

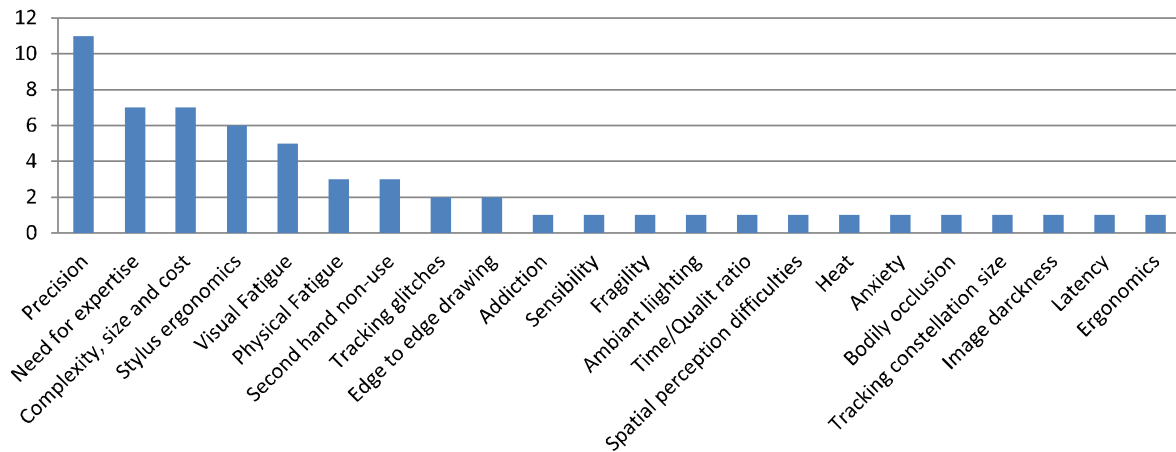


Figure 83 - Feedback on the weaknesses of the immersive early design experience

The *lack of precision*, *need for expertise* and the *complexity, size and cost* of the immersive device are expressed as barriers to the deployment of this experience. However, after ending the immersive design session, the participants frequently ask the price of the system, and express their desire to acquiring one. This questionnaire also enabled the research team to detect a misfit in the design of the stylus (virtual pen), which has a different grip than a traditional pen. Spontaneous verbalizations qualify the virtual pen as being “*too big*” and “*too heavy*” or “*un-balanced*”. Visual and physical fatigue will be approached further in the result analysis. (cf. § 4.3.4.3.5).

The last part of this analysis presents data gathered from a brainstorming intended for the designers to imagine the future features of the system. The following figure (cf. Figure 84) illustrates the common ideas, desires and design needs:

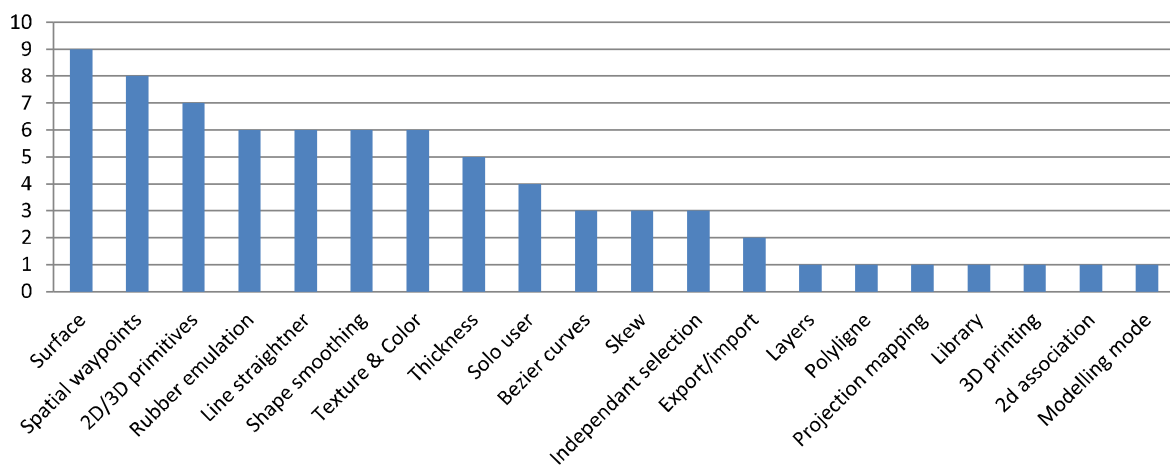


Figure 84 - Desired features for future immersive early design experience versions

A third of the designers express their need for *surface generation* and *manipulation*. A good number of the participants also relate that having more *spatial references* could improve the experience.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Feedbacks on the Immersive early design experience		
				Best features	Weak features	Desired features
Positive features	Immersive early design experience	Early design task & Feedback	Sub-task 7 & 7' & Sub-task 10	Spatial vision & manipulation, Pleasurability, Speed, Simplicity	Precision, Need for expertise, Complexity size and cost of device, stylus ergonomics	Surfacing, Spatial references, Shape primitives, Better rubber emulation, Shape and line smoothing, texture and color

Table 16 - Synthesis of the asset, weaknesses of the Immersive early design

4.3.4.3.4 INSPIRATIONAL IMPACT OF THE DESIGNER

This analysis is the outcome of the *evaluation of the inspirational impact of the moodboards on the concepts* (sub-task 13) produced during the early design task (cf. Table 17). By visually comparing the moodboard and the concepts, a panel of 10 master designers is asked to evaluate the extent to which the designers inspire themselves from the moodboards (cf. Figure 85). The master designers are asked to attribute a score ranging from 0 to 100 for each concept. A score of 0 indicates that the designer has not drawn inspiration from the moodboard whereas a score of 100 signifies that the designer has completely used the moodboard as an inspiration source.

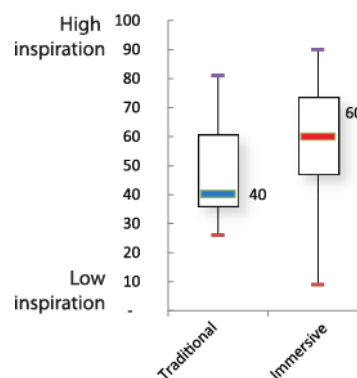


Figure 85 – Average inspiration impact of the moodboard on the concepts

The results show that the immersive moodboard have a greater impact on the concepts. With an average score of 60 point the immersive moodboard inspire x1.5 times more than the traditional moodboard.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of Immersion with regard to traditional workflow
Inspirational impact of moodboards on concepts	Immersive early design experience & Concepts	Early design task & Online concept evaluation	Sub-task 7 & 7' & Sub-task 13	↑ x 1.5 pts

Table 17 - Impact of Immersion on the extent to which the concepts are inspired from the moodboards

4.3.4.3.5 FATIGUE SURVEY

This survey is intended to measure the fatigue phenomenon during immersive early design activity (cf. Table 18). Stereoscopic vision requires an oculo-motor effort as well as a synesthetic cerebral acceptance (Leroy, 2012). The standing posture and dynamic bodily activity is also a factor that can disturb the users' experience.

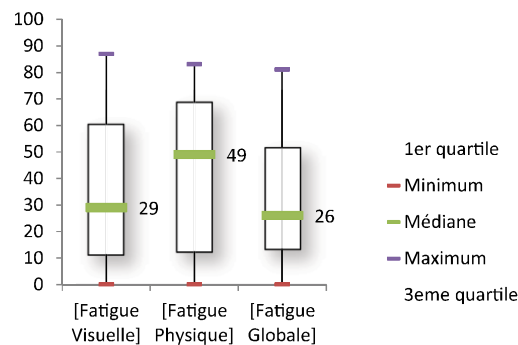


Figure 86 - Effect of 45-60min of early immersive design on fatigue

These results must be understood bearing the fact that the tested participants are in an experimental situation and that they are required a relatively intense activity before and after the design task. At the time the participants are asked to evaluate their fatigue level, they have been in contact with the system during 45 minutes to 1 hour.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Feedbacks on Immersive early design experience		
				Visual Fatigue	Physical Fatigue	Global Fatigue
Fatigue	Immersive early design experience	Early design task & Feedback	Sub-task 7 & 7' & Sub-task 10	Low	Mid	Low

Table 18 - Synthesis of fatigue survey analysis

4.3.4.3.6 KEY RESULTS RELATED TO THE IMMERSIVE EARLY DESIGN EXPERIENCE FEEDBACK EVALUATION

In order to meet the needs of the designer we have designed a tool based on a theorized model the designers' activity as well as on practical ethnographic studies of their tools. The preceding analysis helps us understand how we have met their needs through the experience. This analysis also characterizes the ideal experience of the early immersive design workflow.

The major feedbacks collected in our database suggest that:

Assets of the immersive experience	Flaws of the immersive experience
<ul style="list-style-type: none"> • Provides a <i>high hedonic quality</i>. • The preferred qualities: <i>Innovative, Challenging and Motivating</i> characteristics. • Enables <i>spatial thinking</i> and the proposition of <i>creative concepts</i>. • Is <i>easy to master</i>. • Provides the ability to <i>view and directly manipulate</i> three dimensional contents. • Delivers pleasurable in a <i>speed and the simplicity</i> way. • Provides better inspiration from the moodboard. 	<ul style="list-style-type: none"> • Can still be improved towards a better <i>pragmatic quality</i>. • Needs a better <i>precision</i> and better <i>shaping features</i>. • Requires <i>practice</i>. • Is <i>too complex and costly</i>. • Lacks some better special references. • Assistance, line smoothing and automated system. • Induce a medium physical fatigue level

We can observe that the experience received a broad consensus over its positive emotional impact. "If I had such a system, I would use it daily" was a spontaneous verbalization of the designer that confirms the success of this tool. However we observe that the immersive early design experience is not at its most and can still be improved to fit the industrial designer's expectations.

4.3.4.3.7 DISCUSSION OF THE EXPERIENCE FEEDBACK

There seems to be a causal effect between the lack of precision and of shaping feature and the medium score obtained in *Attrakdiff pragmatic* quality score. The designers are not able to refine their concepts thus the lack of precision keeps them from fully reaching their goals and entering the embodiment phase following the early design activity. The immersive early design experience still lacks the features to easily transfer from the early design activity to the embodiment phase. The proposed new features also result in expressing the designers' need to obtain a neater concept sketch. Primitive shapes, line straightener and shape smoothing are three of the desired features. They may relate to the lack of precision experienced by the participants.

Unlike contemporary computer aided design software, the immersive spatial environment enables the designer to directly express his ideas with gestures rather than with complex geometric systems prompting precise values. As said in the state of the art computer aided design applications are intended to receive as an input the exact characterization of shape (§2.2.4.2)

The results of the prior studies must be put in perspective with the immersive sketching skill. The thirty minutes spent in sketching activity are not enough to acquire sufficient dexterity and bodily control to perfectly externalize a concept. However outside of the experimental framework, we have observed outstanding skills and results following long-term exposure of industrial designers to immersive early design practices. This skill development seems to grow proportionally with the pleasure and need for the immersive early design experience. “...If I could practice more, I would acquire a better dexterity” Here is a collected verbalization that indicates the feel of this designer related to his skill and ability to progress. This indicates that a margin is still available for further progress, quality and pleasure.

4.3.4.4 STUDY OF THE PRELIMINARY TASK

The following sections relate the results providing from the analysis of *preliminary task* (cf. 4.3.3.4.1.1). Its sections present conclusions on:

- First encounter sketching behaviors §4.3.4.4.1
- Impact of the spatial perception on the use of the immersive workflow §4.3.4.4.2
- The impact of the traditional sketching expertise on the immersive sketching expertise §4.3.4.4.3

4.3.4.4.1 FIRST ENCOUNTER SKETCHING BEHAVIORS

The first encounter with the immersive spatial sketching experience was done during the *immersive sketching explanation* (Sub-task6) and *the free sketch* (Sub-task7). After a similar demonstration showing the features of the system, the participants are asked to draw a three dimensional cube (cf. Figure 87). This analysis intends to show to what extent the designers are able to grasp the enabled depth feature when given simple but complete instruction and demonstration (cf. Table 19). 26% of the designer's sketched cubes are two dimensional isometric cubes drawn on a 3D plane. 74% of the designers naturally use the depth enabled by the immersive device on their first attempt.

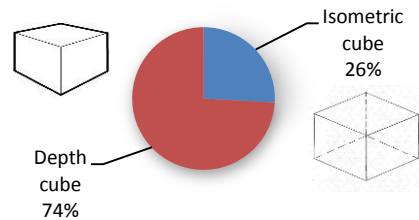


Figure 87 – Understanding depth sketching

Given that $\frac{3}{4}$ of the designers succeed in drawing in depth, this analysis shows how user friendly and natural the interaction scheme is. This analysis also reveals that the failing designers are committed to their drawing knowledge and need a trigger to understand the new paradigm. To adopt the new experience and access spatial immersive sketching, the participant needs to deconstruct his embodied knowledge and relearn how to represent the world and externalize concepts. For instance immersive sketching does not provide a rest for the arm to be guided, thus designers must learn how to draw by triggering the gesture from the hips and legs rather than using the shoulder and elbow as starting point. Though a new set of rules are to be learnt and references must voluntarily be forgotten, some behavior seem to be preserved. For instance many designers rehearsed the gesture without drawing, before drawing a line. This reflex is the symbol of adapted behaviors adopted during traditional drawing. This learning process is based on the designers' body consciousness and the construction of embodied knowledge considering the design sketching as an enactive activity.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Sketching behavior
Depth sketching Trial count	First immersive sketching	Training task	Sub-task 7	74% of immediate depth sketch

Table 19 - Synthesis of the sketching first behavior

4.3.4.4.2 SPATIAL PERCEPTION

The following results are provided from the analysis of the *mental rotation test* (sub-task 1). We have detected no significant difference of mental rotation test between our groups of participants in immersive or traditional condition. We are thus unable to detect the effect of better spatial perception (mental rotation ability) on the performance of a group of designers using the traditional of immersive workflow. Further testing must be done to validate the relevance of this test to this situation as well as to correlate spatial perception to immersive early design activity.

4.3.4.4.3 IMPACT OF THE TRADITIONAL SKETCHING EXPERTISE ON THE IMMERSIVE SKETCHING PERFORMANCE.

Object of measure	Subject of measure	Task(s)	Sub-task(s)	Impact of traditional sketching skills on Immersive sketching performance
Traditional sketching	Immersive sketching performance	Skill related tasks	Sub-task 2 & Sub-task 5	Inconclusive

Table 20 - Synthesis of the mental rotation test analysis

No significant effect is found in the study of this data. The expertise in traditional sketching is not significantly correlated with the performance in immersive concept sketching.

4.3.5 DISCUSSION

The data demonstrate that the emotional activity of the designer is significantly modified on different levels. This section relates and crosses the results obtained in the analysis following EXP2. We will discuss independently the results of the 4 segments of the experimentation.

This section discusses the results obtained in EXP2. Before discussing the whole experimentation focus on the 4 sections of this experiment.

- **Study of the early design task**

This most instructive study shows how the immersive experience of the early design workflow can transform the designer's activity. By modifying his tool we transform his insight on the design problem and add a high emotional component to it. Thus for a similar design problem the designer is resolves it differently when traditional or immersive tools. This modification in design thinking and in experience is revealed through his different use of the time, his overall increased emotional activity. The first figure reports the finding related in the prior sections 1.3.4.1 and 1.3.4.2. These results relate to the studies of the impact of immersion on time management in early design activity and physiological emotional response to early design activity:

Condition	Action Unit Duration		Peak Count		Peak Frequency	
	Traditional	Immersive	Traditional	Immersive	Traditional	Immersive
Inspiration						
Observation						
Sketching						
Deletion						

Table 21 - Impact of immersion on time management and physiological emotional response

The practice of an immersive workflow increases the inspiration activity unit's duration, galvanic skin conductance peak count and galvanic skin conductance peak frequencies. It increases the observation unit duration and peak count whilst decreasing the galvanic skin conductance peak frequency. Furthermore immersive early design decreases the sketching unit duration but increases the galvanic skin conductance peak frequency during the sketching unit.

The peak concentration monitored increase is observed during the immersive sketching and inspiration activity unit. The encapsulating trend environment and the bodily engagement in gesture based sketching are the key elements of the increased emotional activity.

The immersive moodboard engages the designer into a longer and more impactful emotional contact with a trend. The stereoscopic visualization and the three dimensional sketch manipulation induces the designer into spending more time observing his concept but the drop in peak frequency seems to indicate that the traditional observation unit has a higher emotional impact on the designer. This shortens the time during which designers engage sketching activity but significantly increases the emotional impact of this activity on the designer.

We suppose that the timewise modification can be due to three different causes. These changes can result from the novice nature of the designer making them spend nearly an additional third of the time in immersion. The increased immersive use can also be the result of a pleasing and rare experience. A third explanation is linked to the concentration of the user. We have observed designers in immersion losing track of the time due to the mesmerizing quality of the experience.

- **Study of the concepts**

Our study shows that the immersive early design experiment presents an overall increase in concept quality. Seeing the design activity as the expression of the designer's intention towards the end-user considers the object as a message withholding an experience. Our studies suggest that the early immersive design process is a better communication vector to support the expression of a message. In that way the immersion of the designer in an inspirational experience of the end-users related trend optimizes the match between the concepts, the identified end-users needs and ultimately the targeted markets. Our study also proves that the concept aesthetic and originality of the concepts is increased. On the 12 highest scoring concept produced in the experiment 10 are produced in immersive early design. This proves the relevancy of immersion during early design processes.

- **Study of the experience feedback**

EXP2 shows that a broad acceptance of the immersive early design experience. The willingness of the

participants to acquire the system also shows that the designers are ready and have been waiting for this innovative approach of the design tool. The designers related that this tool as fun, pleasing, addictive and mostly corresponding to a need. The immersive early experience seems to have a fulfilling effect on the participants. It also generates great enthusiasm and appear to create needs in the designer's community.

However, the presented results also indicate that there still is a space for optimization.

- The ergonomic aspect of the workspace can be upgraded for the studies have been focused on the design experience and not on the practical and physical aspects of our tools. Stylus size and shape, standing position, size of the device are still experimental factors. Technologies are available so that the experience can be integrated in design studios. This opportunity will be studied.
- In the experience we have developed a number of features enabling immersive design. The low precision along with the absence of features such as primitive shapes and spatial references still need development. This lack keeps from reaching the design goals. Thus the analyses suggest that this lack relate to the experience average score in pragmatic quality.
- The results also indicate that immersive early design uplifts the inspirational impact of the moodboard. A vivid and enactive access to the moodboard must be impactful to memory and generate persistence of design attributes in generational activity.

In general terms, the innovative experience has provided the participants with a pleasurable discovery. A clear wow effect followed by nourished interest shows the success of our work.

4.3.6 CONCLUSION

Ultimately this investigation develops the theory that an emotional link reflecting the designer's intention is felt by the end-user. The more pleasurable and emotional the activity during the early design is the more the resulting concepts induce and aesthetic and unique experience. The immersive early design tools provide a platform for emotional engagement. *"I've been waiting for this (the immersive early design experience) for a long time"* As is detected in the need analysis preformed beforehand, the spatial immersive sketching is part of a designers fantasy tool. This interjection correlates to the high positive emotional value of the experience and the overall the appreciation for the early immersive design experience. We observe that some designer experience an addiction to the tool to the point where they ignore the surrounding happenings and refuse to end the immersive early design experience.

To conclude the following table recalls all the measures operated during EXP2:

§ 3.4.1.1

Object of measure	Subject of measure	Related section(s)	Related step(s)	Impact of Immersion with regard to traditional workflow
Duration	Total early design task	Industrial design task	Sub-task 7 & 7'	↑ + 5 min

§ 3.4.1.2	Object of measure	Subject of measure	Related section(s)		Related step(s)	Impact of Immersion with regard to traditional workflow			
	Duration	Activity Units		Industrial design task	Sub-task 7 & 7'	Inspiration	Observation	Sketching	Deletion
						↓ /1.5 sec	↓ x5.5 sec	↓ /2.5 sec	↑ + 3 sec

§ 3.4.1.1

Object of measure	Subject of measure	Related section(s)	Related step(s)	Impact of Immersion with regard to traditional workflow
Galvanic Skin Conductance peak count	Total early design task	Industrial design task	Sub-task 7 & 7'	↑ x 1.5 peaks

§ 3.4.2.1	Object of measure	Subject of measure	Related section(s)		Related step(s)	Impact of Immersion with regard to traditional workflow			
	Galvanic Skin Conductance peak count	Activity Units		Industrial design task	Sub-task 7 & 7'	Inspiration	Observation	Sketching	Deletion
						↑ x 8 peaks	↑ x 2 peaks	↓ -2 peaks	↓ -2 peaks

§ 3.4.2.3	Object of measure	Subject of measure	Related section(s)		Related step(s)	Impact of Immersion with regard to traditional workflow			
	Galvanic Skin Conductance peak frequency	Activity Units		Industrial design task	Sub-task 7 & 7'	Inspiration	Observation	Sketching	Deletion
						↑ x 6 peaks.min ⁻¹	↓ /3 peaks.min ⁻¹	↑ x 3 peaks.min ⁻¹	↓ /3 peaks.min ⁻¹

§ 3.4.3

Object of measure	Subject of measure	Related section(s)	Related step(s)	Impact of Immersion with regard to traditional workflow
Semantic Proximity	Concepts	Industrial design task & Online concept evaluation	Sub-task 6 & 6', Sub-task 7 & 7' & Sub-task 12	Concept semantic-emotionally closer to Moodboard

Object of measure	Subject of measure	Related section(s)		Related step(s)	Impact of Immersion with regard to traditional workflow		
					Aesthetic	Originality	Intelligibility
§ 3.4.4	Aesthetic, Originality, Intelligibility		Industrial design task & Online concept evaluation	Sub-task 7 & 7' & Sub-task 14			
					↑ Aesthetic	↑ Originality	Similar Intelligibility

Object of measure	Subject of measure	Related section(s)		Related step(s)	Feedbacks on the Immersive early design experience			
					Pragmatic Quality	Hedonic Quality: Identification	Hedonic Quality: Stimulation	Attractiveness
§ 3.4.5.1	Pragmatic Quality, Hedonic Quality & Attractiveness		Industrial design task & Feedbacks	Sub-task 7 & 7' & Sub-task 8				
					Simple and manageable	Connecting and integrating	Inventive, Creative, Innovative, Captivating, Challenging, Original	Pleasant, Agreeable, Engaging, Good, Appealing, Motivating

Object of measure	Subject of measure	Related section(s)		Related step(s)	Feedbacks on the Immersive early design experience	
					Positive feedback	Negative feedback
§ 3.4.5.2	Feedback		Industrial design task & Feedback	Sub-task 7 & 7' & Sub-task 9		
					Spatial reflection, Learning ability, Creative ability, drawing fluidity, externalization ability	Drawing precision, Shape work ability

Object of measure	Subject of measure	Related section(s)		Related step(s)	Feedbacks on the Immersive early design experience		
					Best features	Weak features	Desired features
§ 3.4.5.3	Positive features		Industrial design task & Feedback	Sub-task 7 & 7' & Sub-task 10			
					Spatial vision & manipulation, Pleasurability, Speed, Simplicity	Precision, Need for expertise, Complexity size and cost of device, stylus ergonomics	Surfacing, Spatial references, Shape primitives, Better rubber emulation, Shape and line smoothing, texture and color

Object of measure	Subject of measure	Related section(s)	Related step(s)	Impact of Immersion with regard to traditional workflow	
§ 3.4.6	Inspirational impact of moodboards on concepts	Industrial design task & Online	Sub-task 7 & 7' & Sub-	↑ x 1.5 pts	

		concept evaluation	task 13	
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§ 3.4.7.1	Object of measure	Subject of measure	Related section(s)	Related step(s)	Sketching behavior
	Depth sketching Trial count	First immersive sketching	Training task	Sub- task 7	74% of immediate depth sketch

§ 3.4.7.2	Object of measure	Subject of measure	Related section(s)	Related step(s)	Impact of traditional sketching skills on Immersive sketching performance
	Traditional sketching	Immersive sketching performance	Skill related tasks	Sub- task 2 & Sub- task 5	No impact

§ 3.4.5.3	Object of measure	Subject of measure	Related section(s)		Related step(s)	Feedbacks on Immersive early design experience		
	Fatigue	Immersive early design experience		Industrial design task & Feedback	Sub- task 7 & 7' & Sub- task 10	Visual Fatigue	Physical Fatigue	Global Fatigue
						Low	Mid	Low

Table 22 - EXP2 measures and results summary

4.3.7 LIMITATION OF CURRENT METHODS

This section presents the limitations of the study. We develop three specific limitations in this study. The limitations of EXP2 are the following:

- Discovery of a new workflow

As said in section 4.3.3.1 the participants are professional designers and are trained in the skill of sketching. On the opposite they have a small experience in immersive design tools. The ideal experimental situation would compare participants which have the same amount of practice in traditional and immersive workflows. Given the novel characteristic of the immersive early design experience, we are forced by practical reasons to compare professional traditional designers with novice immersive designers. In an ideal experimental situation, the participants would have been progressively trained to use the immersive sketching tools before being compared to participants in traditional condition. This statement raises the question of learning processes in immersive early design environments. A third of the designers describe the experience as being simple and intuitive,

however a third of the participants also express that they feel can improve their skill, and produce better quality sketches (§4.3.4.3.3)

- Brief design

Our study aims to create knowledge concerning the whole of the product design practices. However by selecting a particular brief oriented towards the design of a precise object for a specific shareholder renders the result objectively interpretable only in this context. This said we justify the design of our brief in section 4.3.3.4.1.2 (sub-section 7&7' p.106).

- Technology dependency

The immersive early experience is delivered by a technical device. The immersive technical system is designed along strict rules and thoroughly based on human factors and enaction theories. However, the immersive environment still depends on technical characteristics such as latency, display type, interaction scheme and the good computation of the user's morphology (§4.3.3.2). Thus our conclusions must be interpreted with regard to knowledge of the variety of immersive system and understanding of the proposed experience.

4.3.8 CONCLUSION OF THE EMPIRICAL STUDY

In chapter IV, we conduct two experiments (EXP1 & EXP2) with professional designers.

The experiments enabled us to compare the immersive early design experience to the traditional early design experience.

EXP1 concerns the immersive experience of moodboards, while EXP2 focuses on a sequential early design process ranging from design brief to concept evaluation and integrating the use of immersive moodboards and immersive sketch.

Based on the user experience model (physiological, psychological and behavioral), on the early design process and our results analyses, we develop three models which detail the impact of immersion on the early design experience, its impact on the semantic and emotional link between the designer and the user and the emotional relationship between the designer and his tools. These models are presented in the following chapter V.

5 CHAPTER V - CONTRIBUTION OF THE RESEARCH

5.1 INTRODUCTION

Chapter V presents our key contributions based on the results from the empirical studies conducted in chapter IV. EXP1 and EXP2 are intended to find how an immersive spatial early design workflow can optimize the inspirational and generational phases of early design. More specifically we develop immersive spatial tools based on the designers needs and their traditional tools. Our research aims to understand the impact of the immersive tools on the experience of the designer during the early design activity. It also enables to depict their impact on the user's product experience through semantics and emotion.

Because we base our research on a model of the design process composed of an inspirational phase followed by a generation phase, we develop 2 immersive experiences corresponding to both of these phases: The *immersive moodboards* and the *immersive sketching*. In order to validate these tools we have implemented an evaluation protocol based on the combined use of questionnaires and measures of physiological and behavioral parameters.

This Chapter consists of 2 sections. The first section develops the academic contribution of this research work in presenting the research models inferred from the obtain results. The second section presents the industrial contribution. More specifically it describes the operational tools assessed by this research work.

- Academic Contribution. (§5.2)
 - Modular framework for designer experience and Kansei measurement based on a multidimensional approach.
 - A comparative model of the emotional processes during the act of immersive early design.
- Industrial Contribution. (§5.3)
 - Immersive moodboards.
 - Immersive sketching.
 - The user experience measurement platform.
 - Specifications for advanced immersive early design experience.

5.2 ACADEMIC CONTRIBUTION

This section relates the academic contributions of this study. The models presented are built on the results found in EXP1 and EXP2. Academic contributions are the following:

- Modular framework for designer experience and Kansei measurement based on a multidimensional approach. §5.2.1
- A comparative model of the emotional activity during immersive early design activity. §5.2.2
 - Emotional content during the immersive early inspiration and generation process.
 - The spatial immersive workspace as a better support for the semantic-emotional link between the designer and the end-user.

5.2.1 MODULAR FRAMEWORK FOR DESIGNER'S EXPERIENCE AND KANSEI MEASUREMENT BASED ON A MULTIDIMENSIONAL APPROACH.

Our research team is focused on digitalization of the design process for its optimization. The presented framework is structured to assess the designer's and end-user semantic and emotional experience and the related Kansei (cf. Figure 88). However, its modular architecture based on cognitive psychology science, physiology and behavioral sciences can extend its application to any kind of user experiences. The benefit provided by this research framework comes from the cross measurement enabling a better objectivity over the analysis of data. This specific configuration is aimed at understanding the Kansei related to the immersive and traditional design representations. The modular architecture of this framework enables the plug-in of any desired measure related to the three categories (ψ , φ , β).

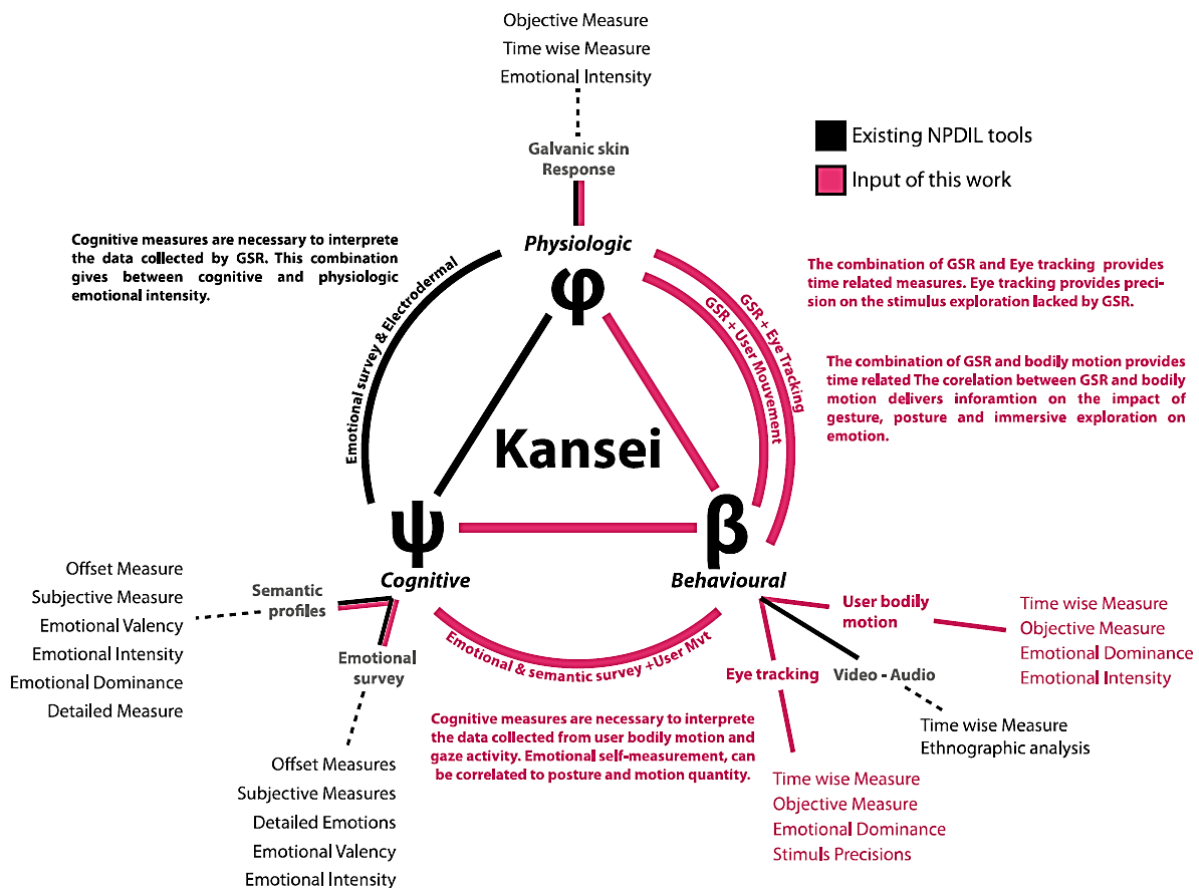


Figure 88 - Kansei measurement model

This model provides correlation between the different measured dimensions. It also allows a complete emotional measurement based on emotional valence, intensity and dominance. The model supplements its subjective measures with objective data and conversely. While subjective measures help interpret the data owing to their precision, they are not foolproof and can be skewed. Objective measures however, give truthful data but are difficult to link back to stimulation. For instance GSC peak does not provide data on the stimulus but only on the response thus drawing a conclusion on causality is difficult without the use of cognitive measures or eye tracking. The correlations of different data sources are necessary to interpret an object as unstable and volatile as emotions. This model is constantly evolving in response the research units need. For each executed experiment, the model is updated given the new results and data combination possibilities. Thus the model is adaptive and kept up to date. In view of future optimization of this model, different measures like facial emotion and pupillary diameter are presently under study and will soon be integrated. Our contribution to the existing NPDIL measurement procedure is the connection between behavioral and physiological data as well as behavioral to cognitive data. Specifically, bodily motion along with data processing methods such as the application of statistical analysis on the fusion of eye tracking with

galvanic skin response .

This model is applied to probe the emotional state of the designer and of the end-user from end to end of the early design process. It gives us access to the emotional state and enables correlation between data observed at different measure points along the observed process. The next section depicts the finding related to the impact of a spatial immersive workflow on the early design experience.

5.2.2 A COMPARATIVE MODEL OF THE EMOTIONAL ACTIVITY DURING THE ACT OF IMMERSIVE EARLY DESIGN.

Our research leads us to a comparative model of the semantic and emotional activity in early design and combined to a model of the impact of this activity on the designers' concepts (cf. Figure 90). This model framework is based on three dimensions. The first dimension is to be read from left to rights. It presents the inspiration and generation phases of the early design process in a timewise fashion. The second dimension opposing the top red section of the figure to low blue section refers to the *immersive condition* and the *traditional condition*. The third dimension relates to the experience based on the model presented in the prior section (cf. Figure 89).

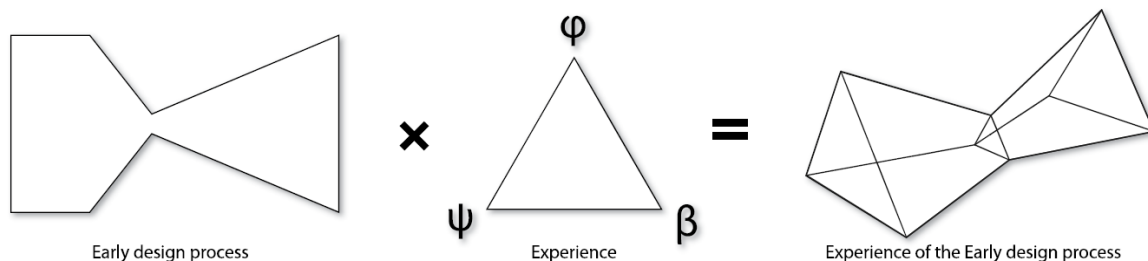


Figure 89 – Modeling of the early design experience

This model describes the phenomenon observed along those three dimensions. Specifically this model reveals the major differences that we have detected between the immersive and traditional experience of the designer and of the end-user along the early design process.

The emotional activity during early design and the concepts which are the product of this activity are modified by a transposition of the traditional early design workflow into a spatial immersive workflow. The emotional activity during early design and the concepts which are the product of this activity are modified by a transposition of the traditional early design workflow into a spatial immersive workflow.

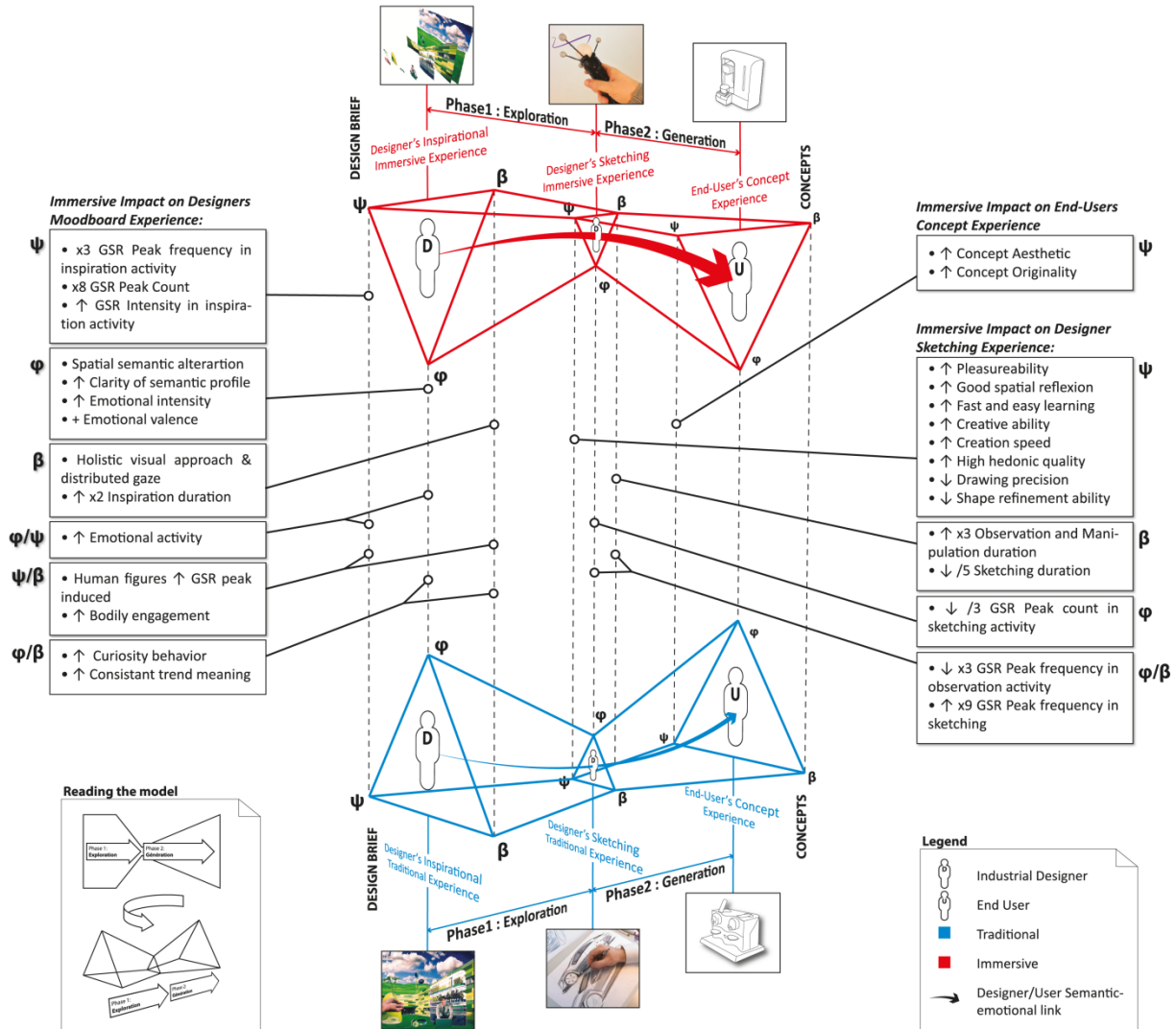


Figure 90 – Comparison of then semantic-emotional activity during the activity during the immersive and traditional early design activity

This model presents our finding on the evolution from traditional design process to an immersive one. We observe that many of the measured parameters have been impacted by our condition:

- The emotional activity during inspiration and generation is increased by a spatial immersive early design experience.
- The immersive moodboard induce a meaningful experience for the conveyed a similar semantic profile to the all the designers.
- The immersive sketching experience triggers an efficient design activity. Furthermore the designers enjoy it.
- The concepts produced by the designer in immersive early design activity convey appropriate semantic and emotional attributes to the end-user.
- The immersive condition significantly improves the aesthetic and the originality of the produced concepts.

An insight on our research and on the existing literature enables us to present an innovative point of view on the mechanisms operating during the early design process. The first observed changes relates to the relationship between the designer's emotions and his experience through this tools. The second change relates to the relationship between the designer and the user. The next two sections detail the listed changes induced by immersion on the early design process.

5.2.2.1 EMOTIONAL CONTENT RELATED TO THE IMMERSIVE EARLY DESIGN PROCESS (INSPIRATION AND GENERATION)

According to experimental results, the inspirational phase and the generation phase are embedded in one another. The generation phase is an iterative mental and manual process of imagining the future product *seeing as*, externalizing the crystalized ideas and assessing the work done *seeing that*. The *Seeing-drawing-seeing* model developed by Schön and Wiggins (Schön & Wiggins, 1992) implies that the designer generates knowledge through sketches using his eye-hand coordination. Our research proves that as visual information is conveyed to or from the sketch, the industrial designers' thriving emotional activity impacts the semantic-emotional content of the concept sketches he produces (§ 4.3.4.1.6). We propose a new model characterizing the immersive early design and based on the cycle of sketching and creating knowledge, focused on the emotional component of early industrial design:

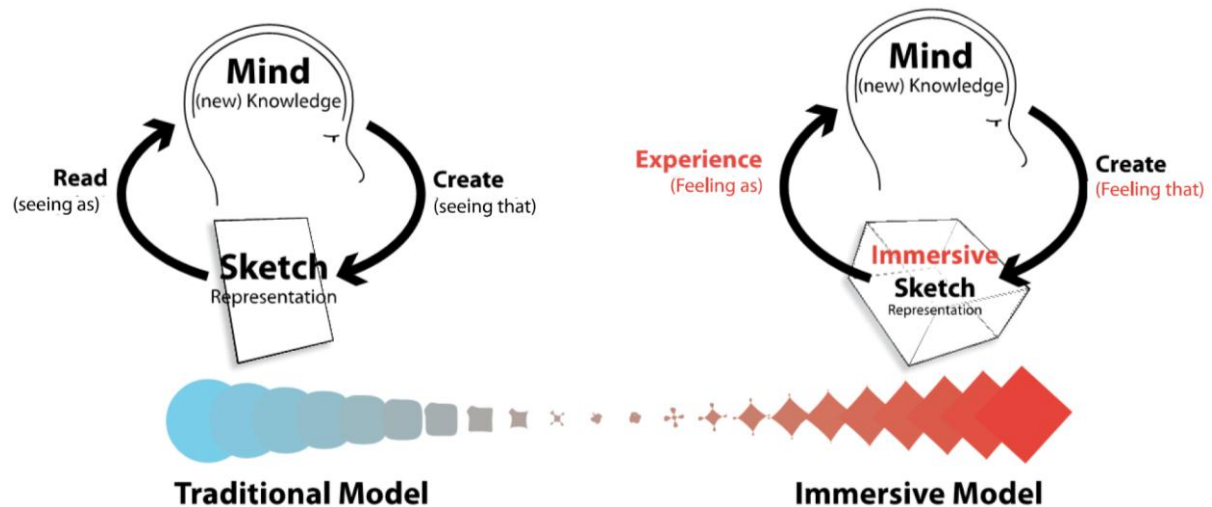


Figure 91 – Feeling Sketching Feeling

Viewing industrial design as the intention of triggering emotions with a product, it is most important that the model is to be considered as "*feeling – sketching - feeling*". The emotional engagement orients and supports the design related decisions. Thus the immersive early design reveals the need for an *emotional dialogue* between the designer, his tools, the designed product and the end-user. This statement justifies the research on effective tools set to vector a large emotional bandwidth with

much intensity.

Virtual reality techniques produce an enactive experience which provides a natural access to a spatial immersive activity. This result enables a fluid interaction between metal design tasks and embodied skills. A good practice of industrial design implies that the designer is in close contact with his tools. Specifically the tool must become part of him as an extension of his power to act (Heidegger, 1927). This process displaces the designers' conscience point from the tool and physical world toward the design problem and more abstract concerns. The opportunity provided by immersive technologies enable the merging of the reality of the designer and that of its tool thus to creating contact between him and an advanced targeted tools. The design of the early immersive experience succeeds in inducing the designer to focus quickly on the design problem rather than on the tool itself. If the first step into the experience requires the discovery through physical and feature identification, the designer seems very quickly projected into an engaging dialogue with his design. The next section presents how the immersive early design process provides an innovative relationship between the end-user and the designer.

5.2.2.2 CONSIDERING THE SPATIAL IMMERSIVE WORKSPACE AS A BETTER SUPPORT FOR THE SEMANTIC-EMOTIONAL LINK BETWEEN THE DESIGNER TO THE END-USER.

Our results show two parallel major phenomenon's induced by an immersive early design workflow (cf. Figure 92). The first one is the increase of the emotional activity experienced by the designer during the inspirational and generational phases. The second phenomenon is the increase of the concept *aesthetics* and *originality* as well as the consistency between the semantic and emotional attributes projected by the designer and those felt by the end-user.

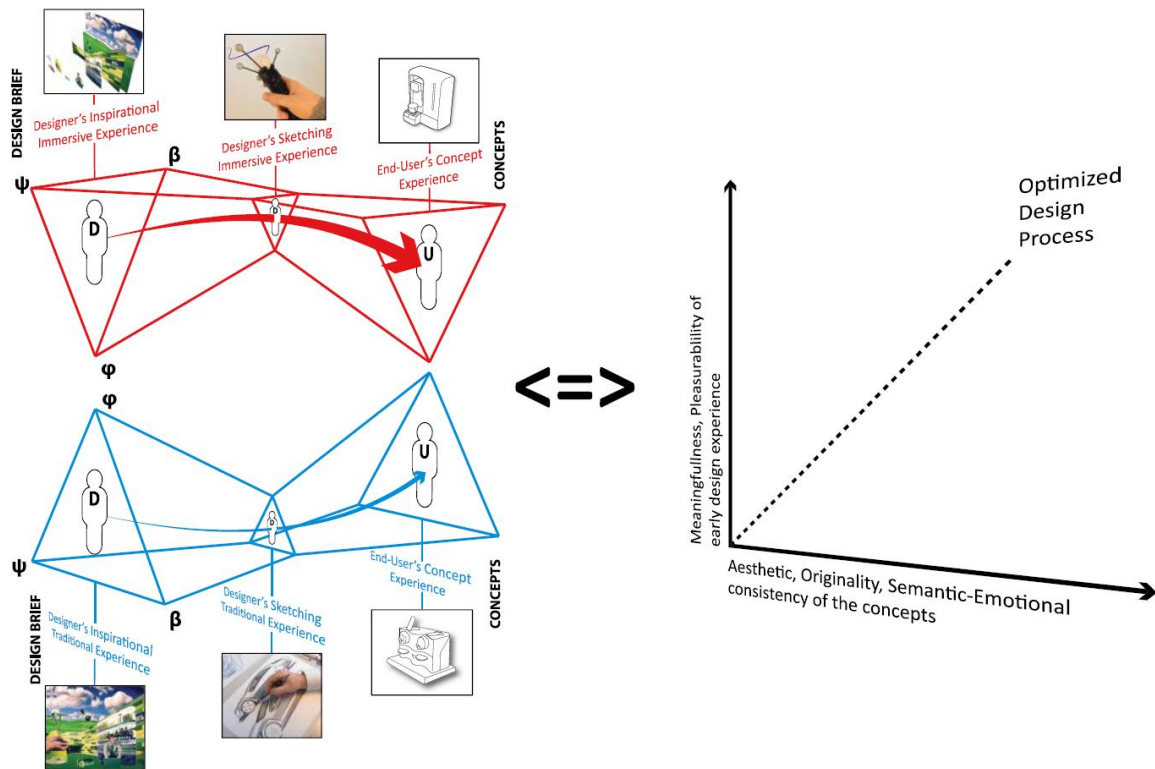


Figure 92 –Immersive early design workflow as an appropriate semantic-emotional vector

We observe that the immersive condition increases the *semantic* and *emotional* experience of the designer as well as the *aesthetic*, *originality* and the semantic and emotional *adequateness* of the concepts. These increases suggest that the better the early design experience is, the more the concepts are *semantically* and *emotionally* adequate in addition to being more *aesthetic* and *original*. Thus this suggests that empowering the designer with immersive tools impacts the concepts quality.

This improved experience triggers a better understanding and feeling of the design problems and engages better choices relating to the end-users experience. This is the resulting effect of the design of an enactive based tool. Industrial design tools raising awareness of style through a rich experience induce an increase in the end-users experience quality. Specifically our results imply that in order to design an experience one must have the capacity to experience. The immersive experience brings the designer closer to the creation of experiences for it provides the ability to deeply assess experiences. To induce a feel, one must feel. (Heidegger, 1927)

5.3 INDUSTRIAL CONTRIBUTION

This section relates the industrial contributions of this study. We will develop the following contributions along this plan.

- Immersive moodboard
- Immersive sketching tool
- The user experience measurement tool
- Specifications for advanced immersive early design experience
 - Input with respect to moodboards
 - Input with respect to traditional sketches
 - Input with respect to Computer Aided Design
 - Conclusion

5.3.1 THE IMMERSIVE MOODBOARD

The first immersive tool we develop is immersive moodboards. This tool enables the designer to engage in design project and test atmospheres by evolving in the trend. This trend sets a reference experience on which his work can be based during the future phases of design such as the generation phase. The immersion in an ambiance enables the designer to operate style related decisions by referring to his experience of the trend. This tool is validated with the deployed of the immersive user experience measurement platform presented in the academic contributions (§5.2.1). Applied to the industry the immersive early design workspace helps the designer in addressing the market with the correct form features. It allows the designer to propose the appropriate concept to the targeted population. Integrated to the product lifecycle management, the immersive early experience enables the rapid production of three dimensional concepts. Thus it brings closer the early design phase to the physical prototyping phase (cf. Figure 98). In addition, based on the serious gaming theories, proposing a pleasurable activity to a working force adds to the high degree of resource concentration in the commitment to the designers task (Csíkszentmihályi, 1990). The democratization of three dimensional content will soon enable the design of immersive inspirational environments composed with 3D models instead of billboards.

5.3.2 THE IMMERSIVE SKETCHING TOOL

Next we approach the concept generation phase in immersive environment. The goal here is to maximize the designers' capacity to put adequate formal concepts into effect. Contrary to the paper and pen, this immersive sketching experience enables the designer to confront his ideas to three dimension. This device offers different features such as color selection, layer management, live shape

assessment, interactive scale and point of view modification (cf. Figure 93).

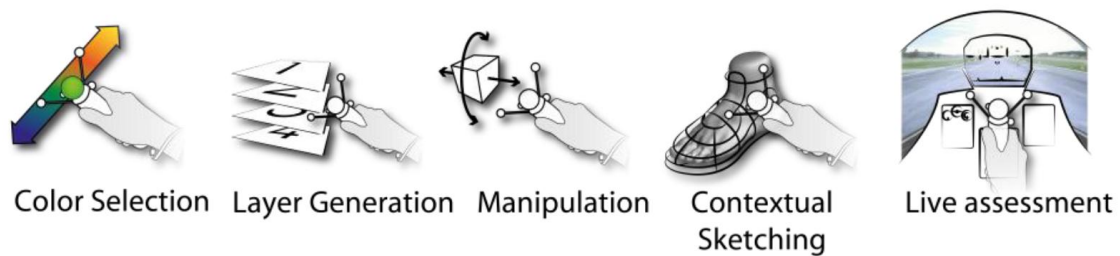


Figure 93 - Immersive sketching features

This immersive device radically changes the relation between the designer and his tool. For instance, it is possible for a designer working on a $1/1$ scale motorbike frame to sketch a seat and then sketch the handlebar to the desired proportions while sitting on the bike in a riding position. The experience as it is enables the designer to contextually draw on an existing object or human being positioned in the interaction space. By analogy with traditional sketching this feature can be used as tracing paper to copy, modify, and add information to the real world. This recast of the re-design process or human centered design process focuses on an existing, tangible object or person. This enables the literal practice of human centered design (cf. Figure 94)

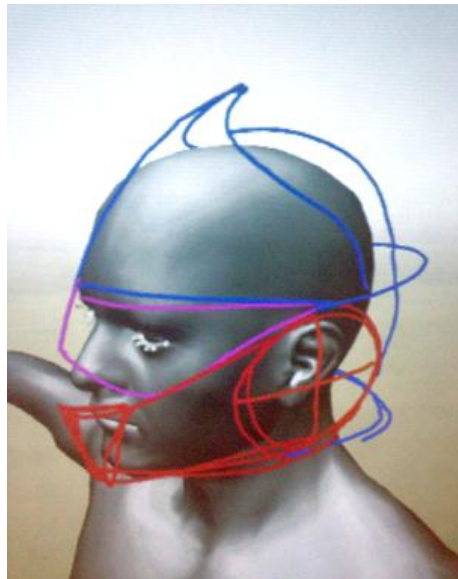


Figure 94 – Using human factor as specification for human center RAJOUTER DES PHOTOS

We have shown the positive changes induced by these individual tools. However, the conjoint use of the immersive moodboard and immersive sketching tool reveals the power and efficiency of our immersive workflow. For instance the designer is given the opportunity to draw directly in an immersive spatial environment. Thus reinterpret the interesting shape attributes, appreciate the

inspirational environment and assess his concept based on his experience.

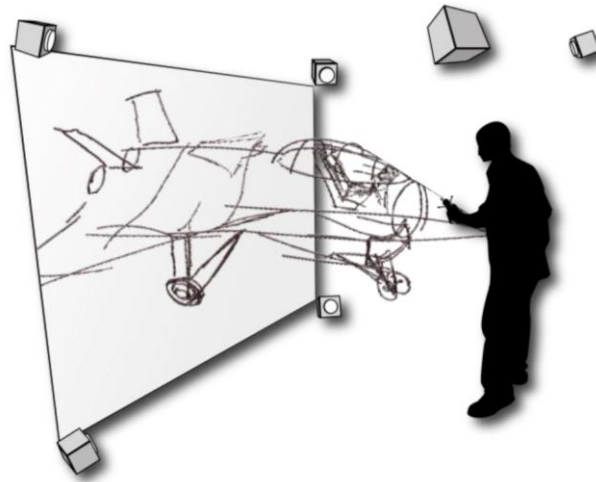


Figure 95 - Immersive sketch

During the early design activity the designer does not work on the geometrical exactitude of shapes but on the shape momentum pushing towards style (cf. Figure 96). This tool enables a gesture based relationship with shape (cf. Figure 95). This positioning is radically different to that of three dimensional industrial design contemporary tools.

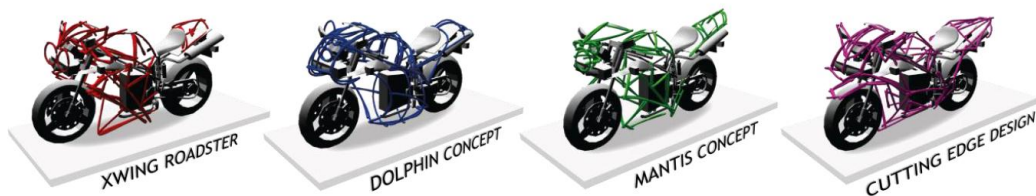


Figure 96 - Style exploration ability of the immersive sketching tool

Immersive environment are constructed to appear spatially realistic to their user. Thus the virtual reality is a digital environment built along enactive, perceptual, sensorial rules. This renders the experience universal thus creating a clear and universal message. Using the 3D representation language for early design enables the designer to communicate his constraints and strategic choices to other teams and expertise (Buxton, 2007). Conversely, this system enables anyone from the marketer to the end-user to intervene on the design concept. This opportunity is a solution to a longstanding communication problem between the engineer and the industrial designer. The next figure (cf. Figure 97) shows the result of collaboration between engineering and industrial designer during the early design activity. This figure shows how the engineer has positioned key elements of the architecture relating to the driving dynamic mechanic such as wheelbase, seat height and rough engine block position. On the other hand the industrial designer has expressed the aggressive feel

and shapes required for this concept. Thus this communicative medium enables concurrent design and fluid communication between design teams (cf. Figure 97).

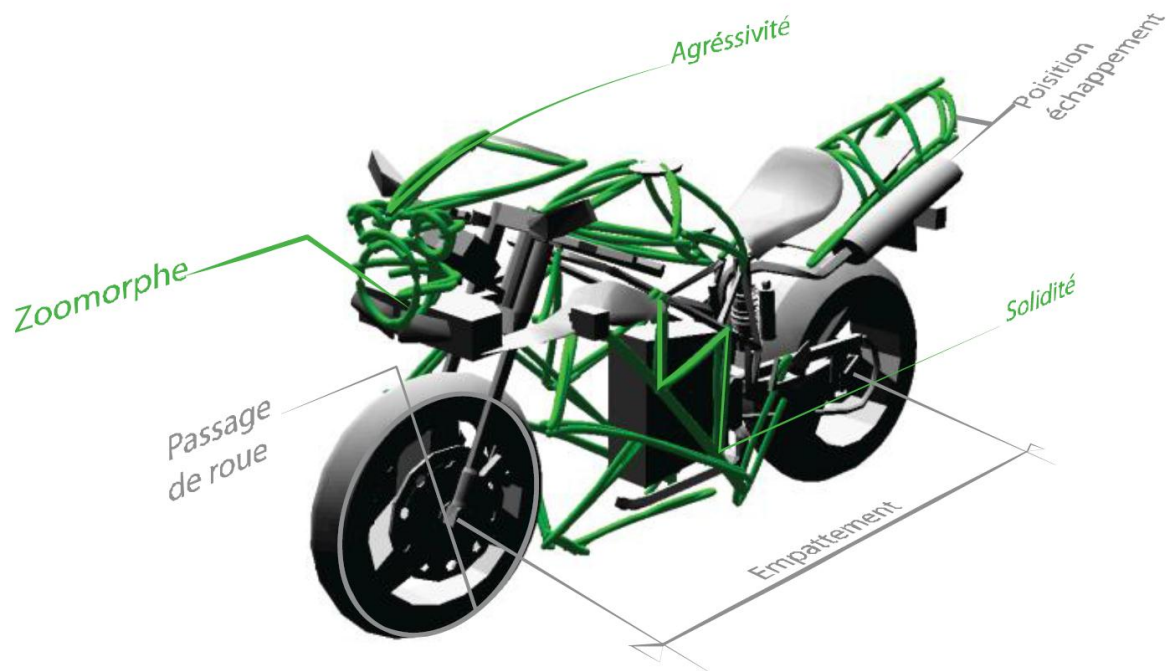


Figure 97 - Immersive three dimension as a common language

In a traditional design process the intermediate representation act as an interdisciplinary vector. The difference existing in the representational language and the ambiguity of understanding induces a drift that can extensively transform the product on all levels. In that sense early design tools should be designed so that no information is lost when the intermediate representations are use further steps in the design process. The development of the sketching tool is directed towards the safeguard of the concept fidelity from idea to final product. By empowering the industrial designer with immersive early design tools the workflow enables the expression of three dimensional messages containing precise information on the shape of the concept.

In addition, we have found that the emotional engagement of the designer into the experience induces positive emotions. The bodily engagement of the designer participates in rendering the early design enjoyable. As research in serious gaming has proven, adding pleasurable aspects to an activity can increase the performance of the designer (Kruglanski A. W., 1996).

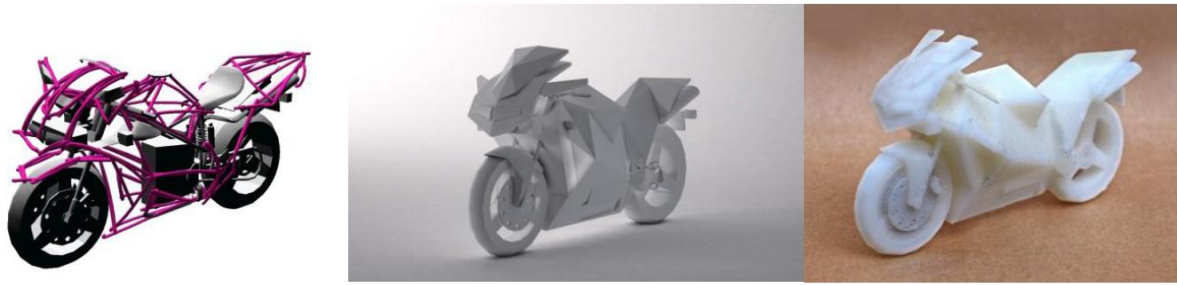


Figure 98 - From Immersive sketch to 3D printing

The early design workflow is integrated to the traditional product life cycle. For instance the model shown in Figure 98 was drawn in less than 5 minutes and converted to an exploitable Computer Aided Design model in an hour. This process is experimental and we evaluate that it can easily be reduced by a ratio of 3.

The lines designed in the immersive sketch, as in traditionally sketch are slightly exaggerated in order to give dynamic to the concept and need to be skewed in order to obtain a valid product (cf Figure 98). However, the design process is largely shortened by the fast production of three dimensional data in the front end of the design process. The model outputted from the sketching tool contains formal key points on which to base the detailed modeling for an optimized fidelity between idea and final concept

The next section presents the industrial contribution related to the measurement of user experience.

5.3.3 THE IMMERSIVE USER EXPERIENCE MEASUREMENT PLATFORM

The emotional measurement platform is dedicated to the evaluation of the user experience (cf. Figure 99). Its design is based on the theatrical models developed as the academic input of this research work (cf. Figure 88). It is been deployed to assess the emotional activity of a design in immersive workflow. This set of tool provides objective data that enable the analysis of the emotion and the behavior of a user. This platform was designed for two purposes:

- Detect the emotions of an immersive user such as industrial designer
- Understand how the concepts resulting of an immersive early design workflow are semantically and emotionally received by the end-user.



Figure 99 - Equipped Designer

The data collected by this system conveys information on which can be based design guidelines or objectives for the construction of an optimized early design experience but also for the design of innovative products. In addition, the application of holistic models and advanced measurement technologies has enabled to thoroughly collect the data, and provide trustworthy interpretations.

5.3.4 SPECIFICATIONS FOR AN ADVANCED IMMERSIVE EARLY DESIGN EXPERIENCE.

Compared to the traditional design process, the immersive tools we propose provide a better interaction between the early design content and the industrial designer. Contemporary Computer Aided Design requires an advanced knowledge of digital geometric models and features. These kinds of software refer to complex formulas describing finite geometries. The lack of knowledge concerning shaping related functions of software can initiate a time consuming trial-error process. The tool can also incite a drift towards technological driven shapes rather than a user-centered design. The wrongly constructed Computer Aided Design tools have conserved un-innovative traditional methods for not answering the needs of early industrial design, hence engendering the term "*Pencil before Pixel*" (Baskinger, 2008). Virtual reality has for a long time been considered as expansive, complex and un-intuitive (Pei, 2009) and it was measured as the least used tool for industrial design (Engelbrektsson & Södermana, 2004). The progress in this domain has rendered virtual reality a part of one's everyday life. And the development methods now enable precise experience. The next paragraphs relate the specifications necessary to a valid early design workflow (cf. Table 23). As the

early immersive experience is hybrid between computer aided devices, sketches and moodboards we have identified assets of the present Immersive Early Design Experience based on a comparison with those tools.

Comparison type	Detail
Specification with regard to traditional moodboards	Embed human figure as an emotional trigger
	Anticipate the spatial composition
	Provide a large interaction space
Specification with regard to traditional sketch	Enable spatial visualization
	Give access to spatial manipulation
	Bodily multisensory interaction
Specification with regard to traditional Computer Aided Design software	Ensure an enactive relationship with design content
	Provide a fast learning curve
	Enable a quick generative speed
	Ensure ability to reaching formal goals
	Allow ambiguity and roughness

Table 23- Relative specifications for an immersive early design experience

5.3.4.1 INPUT WITH RESPECT TO TRADITIONAL MOODBOARDS

- Human figure emotional trigger

Our research show that human figure generate high intensity emotions in traditional and immersive moodboards. Thus when composing a moodboard with a character this one must be carefully chosen in order to suggest the right message and induce a targeted experience.

- Spatial composition

The results of our experiments show that the semantic-emotional profiles may vary on spatial related thematic. Thus the composition of the spatial immersive moodboard differs from that of the traditional moodboard composition. One must anticipate the effect of immersive spatialization. We have observed that the spatial immersive moodboards feel more open, large and spacious.

- Provide a wide interaction space

For experimental purposes the real space in which the designer is able to experience the moodboard in EXP1 is a volume measuring 1.5x1.5x3 m. EXP2 provides an interaction space of 3x3x3 m. The more interaction space is given to the user the more this space is explored.

5.3.4.2 INPUT WITH RESPECT TO TRADITIONAL SKETCHES

- Immersive spatial visualization

In comparison with traditional sketches the first appreciated aspect of the immersive sketching tool is capacity of the designer to modify its point of view in order to draw and perceive three dimensional sketches. The perspective recalculation is most immersive characteristic of this experience and thus must be implemented to obtain satisfying results.

- 3D for manipulation

The capacity of the designer to grab, pan, tilt and skew the drawn sketches adds to the thrill and practicality of the experience. The device supports manipulation in order give the designer full access to the virtual environment and to the design occurring in it. These features are the core of a pleasurable and pragmatic early design experience.

- Multisensory and whole bodily

Bodily interaction with the system stimulates haptic and visual modality of the senses. This synesthetic feedback can generate sensorial illusions such as the haptic feeling of breaking through a sketch. A good coherence between multisensory data is crucial to create a fully engaging experience. Audio and vibratory feedbacks are also available in the experience.

5.3.4.3 INPUT WITH RESPECT TO COMPUTER AIDED DESIGN

- Enactive relationship with design contents:

The use of natural interaction schemes renders a clear and simple experience. The designers need an interaction as simple as that offered by their traditional three dimensional tools. Thus the system needs instinctive functions providing the possibility spontaneous externalization to fit the early immersive design. Our tool was qualified by the designers as fast, simple and fluid and it provides and enjoyable design activity.

- Fast learning curve

The complexity of the contemporary Computer Aided Design software can takes months to master. Natural interaction contributes to the small time required for a designer to get up to speed. Observing the industrial designer's needs has enabled our research and development team to architecture the immersive early design with regard to the early design traditional. Providing analogies to the pen rather than to geometrical functions contributes to a fast familiarization with the tool. We have found that relating to the traditional tacit knowledge of the designer such as the

visualization of shapes with cross-section lines is rewarding. (Erik Olofsson, 2007) In addition we have observed that the designer uses part of their bodily knowledge in the immersive early design experience.

- Quick generative speed

The immersive early sketching tool gives access to three dimensions in a very fast fashion. That is to say it fulfills the need of the designer for immediate feedback. This speed is required and appreciated by the designer for it enables quick iterations between generation and assessment of the concept state (*seeing-as / seeing-that*). Thus this speed permits the exploration of a wide range of concepts or details a concept in the same amount of time. In addition, it is a critical function for the sketch to be timely and provided when needed.

- Reaching formal goals

Usability and pleasurability are the two prior factors in user experience. A tool providing good industrial design usability enables the designer to express what he intends to with a high fidelity. Computer Aided Design software can generate frustration, for the complexity or time consumption of complex shape generation can induce the designer into making cutbacks into his intention. In no way must the design process be limited by such problems.

- Ambiguity & Roughness

An immersive sketching system dedicated to early design needs to provide the designer with a good level of ambiguity. This ambiguity serves the design because it leaves way for thinking and enables the identification of design solution shortage rather than freezing solutions. In that way the immersive sketching application requires the possibility for the designer to express the unfinished and rough state of his concept. Our take on this issue is to enable only wire sketching rather than surface so that the designer is constraint to using cross section representations thus leaving space for refinement.

The experimental early immersive sketching tool is voluntarily kept simple so that the relationship between the design and his immersive concept sketch are brought closer to one another. The plentiful functionalities found in Computer Aided Design software are either related to the refinement phase of the design process such as detail editing or provided to supplement the lack of accessibility to the infinite variety of possible shapes.

5.3.5 KEY CONTRIBUTION TO THE SPECIFICATION OF THE IMMERSIVE EARLY DESIGN EXPERIENCE

Our research work has brought 4 major specifications for the design of an immersive early design:

- An immersive early design should be developed following a traditional interaction design innovation method which aims at conserving at its most traditional uses and knowledge's while providing innovative enhanced abilities.
- Natural interaction and the fusion of the moodboard, of the sketch, and the real world assist the designer in projecting himself in his design and in the inspirational environments.
- An efficient immersive early design workflow should to provide an enactive and fast access to design. The designer must obtain direct feedback of a bodily action intended as a generative trial.
- The use of three dimensional representations during the early design activity helps in communicating key information in a universal language.

5.3.6 SYNTHESIS OF THE CONTRIBUTION OF WORK

This research work is driven from conjoint academic and industrial objectives. The dynamic merging our research to the professional practices provided by the research & action method of the NPDIL, has proven to be benefic both to the academic and the industrial domains. The early design research domains gain from the models presented as the contribution of this research work and the professional designer benefits from practical tools developed from his registered needs. Both our objectives of understanding the activity of the industrial designer working in immersive environment and developing a fitted innovative workflow are met. Our original point of view on early design, emotions and immersive experience has unlocked the development of an innovative practice and its theory. This contribution opens a way towards a research thematic on immersive early design and the ideal morphology of the embed tools for a better process.

6 CHAPTER IV – CONCLUSION AND PERSPECTIVES

6.1 CONCLUSION

This thesis focuses on the contribution of the immersive experience to the early inspirational and generational design activity. Within the early design activity the designer externalizes his concepts. Concept generation is based to a certain extent on his inspiration and by using a generation tool. This early design process and the appraisal of its resulting products are both based on a semantic – emotional experience. We model the impact of immersion on the early design activity and of its modification of the early design process's outcome. Based on a fusion of the physiological, psychological, and behavioral component of the designer experience upon the inspirational and generational phases of the early design activity, we model the changes induced by a spatial immersive workflow.

Our empirical study has enabled (EXP1) the quantification of emotional and semantic processes during the inspirational phase and (EXP2) the qualification of the early designer and user experience throughout a condensed early design process ranging from brief to concept evaluation. Our experimental approach has enabled the identification of three major impacts induced by an immersive early design activity. The impacts are the following:

1. Enhancement of the early design experience emotional component;
2. Increase in concept aesthetic and originality;
3. Improved relationship between the designer's semantic and emotional intent and the users semantic-emotional experience.

These results have yielded two models concerning the impact of immersion on the early design activity. The models are the following:

The first model, relate to the designer's experience of his early immersive activity, by explaining how the immersive moodboard and sketching experience induce changes in the psychological, physiological and behavioral dimensions of the experience. This model integrates subtle information on the induced changes relating to the experiential dimension impacted and to the stage of early design to which it belongs.

The second model introduces the link between the early design activity designer's experience and the user's experience of the produced concepts. More specifically it relates how the emotionally and meaningfully enriched experience occurring during the immersive early design activity can positively impact the *aesthetics*, *originality* of the produced concepts. In addition the model relates the correlation between an immersion and the enhancement of the relationship between the designer's

semantic-emotional intent and the user's semantic-emotional experience.

6.2 PERSPECTIVES

Our research proposes a new breed of early **design** tools. Future research should be focused on the further understanding the complete reach of these tools inside and outside of the design framework. The following perspectives are however, focused on the design related perspectives. The next three sections propose perspectives of our work with regard to short, medium and long term timeframes.

6.2.1 SHORT TERM PERSPECTIVES

The limitations of our study as well as research thematic identified through our research practice has forged an idea the upcoming research embodiment.

Future research should:

- Study the early design experience of designers who have acquired skills in immersive early design.
- Analyze how the early immersive experience can be adapted to a desktop version in order to bring the tool in design studios and to test the performance of designers working on ongoing projects in a their natural environments.
- Develop a multi-user version of the experience in order to study the impact of immersion on multidisciplinary and distant early design related decision making.
- Study the impact of multisensory stimulation during the inspiration phase of the early design activity. Concepts like soundscapes and tactile charts can easily be added to the immersive moodboards
- Take in account the feedback, emotional data and desires unveiled by our study in order to develop a better version of the early immersive experiences.

6.2.2 MEDIUM TERM PERSPECTIVES

The NPDIL has been developing computerized model of the design activity and implementing them

into innovative and efficient tools for more than 10 years. Future research are to be undertaken in order to enable communication between every tools and ultimately to deliver and end to end improved design process. This process can only be developed owing to future research on ubiquity and further studies of the informational motion in design.

The information collected during this research work has exposed the emotional actives induced by an immersive early design experience. Yet in the continuity of the NPDIL research domains still need workforce within the combined frontiers of designer centered design, affective computing and artificial intelligence. Based on the result of this thesis, research can be engaged on the development of a responsive design interface which can takes in account the emotional state of the designer and dynamically propose adequate content and features in order to optimize the design process.

The developed user experience measurement platform presently integrates the most interesting measures for our analyses. However, as methodology and technologies evolve, new, precise and unobtrusive experience related measurements are developed. Research work must be engaged on the optimization of the current experience measurement platform related to the physiological, psychological and behavioral dimensions. A practical testing of the wide range of existing measures will provide extensive information on which the upgrade of this measurement platform can be based.

6.2.3 LONG TERM PERSPECTIVES

Ultimately our research and development team has provided the industrial design with a new upgraded experience of his activity. Effort must be kept towards the development of an accessible and pleasing product design process. This process must maximize the fidelity between the ideas of the designer, the desire of the user and final product experience in order to optimize the product lifecycle. An essential attention to the pleasurability and access to intermediate assessment of the experience will guarantee a universal acceptance of the innovative tools and of the products they provide.

In a near future, the development of additive prototyping system will enable instant physical modeling of the designer early mental concepts. Our research describes how to engage the designer into a correct relationship with generative tools. A long term research must be engaged to fuse contemporary immersive tools to rapid prototyping systems.

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